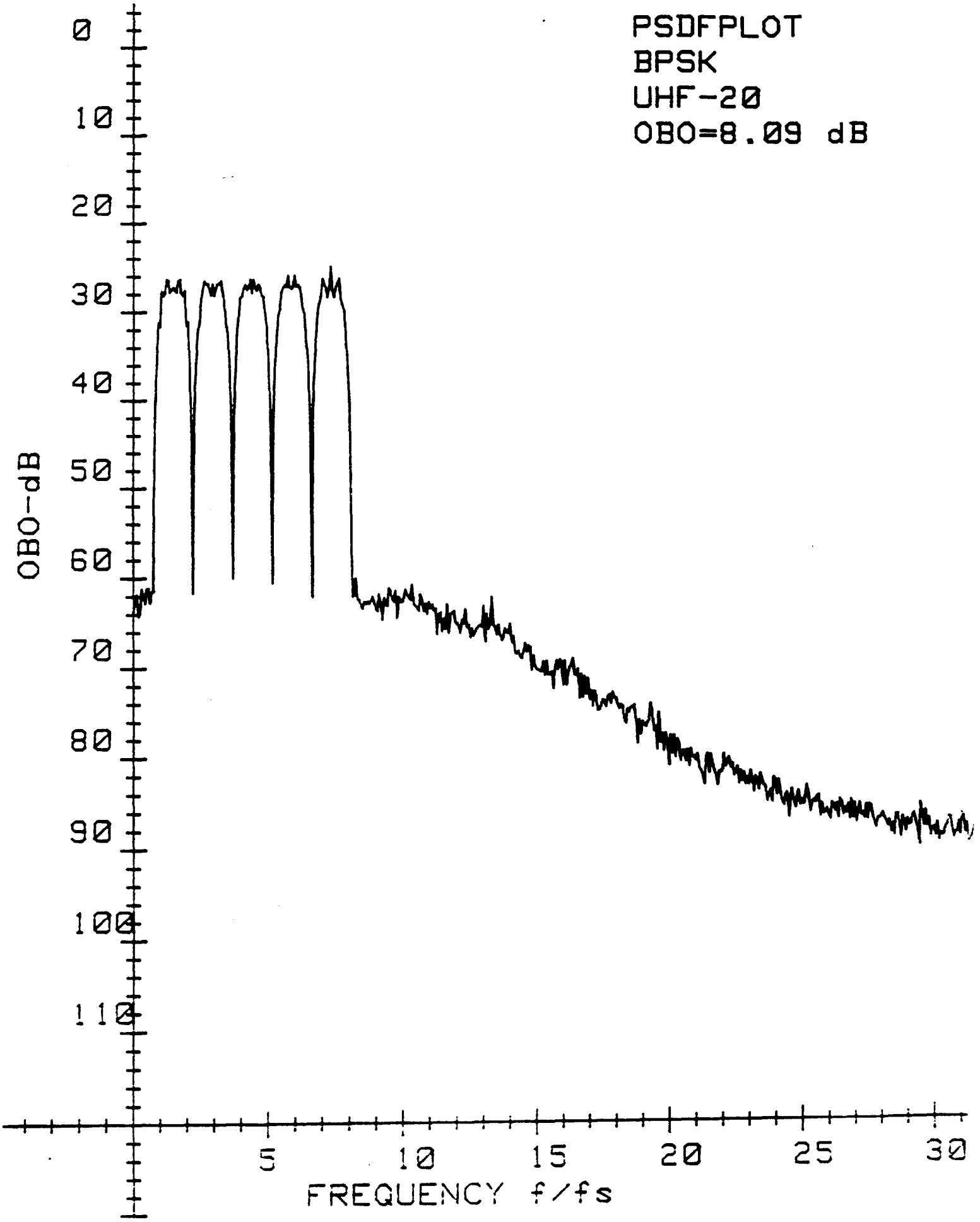
PSDFPLOT
BPSK
UHF-20
OBO=8.09 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 6

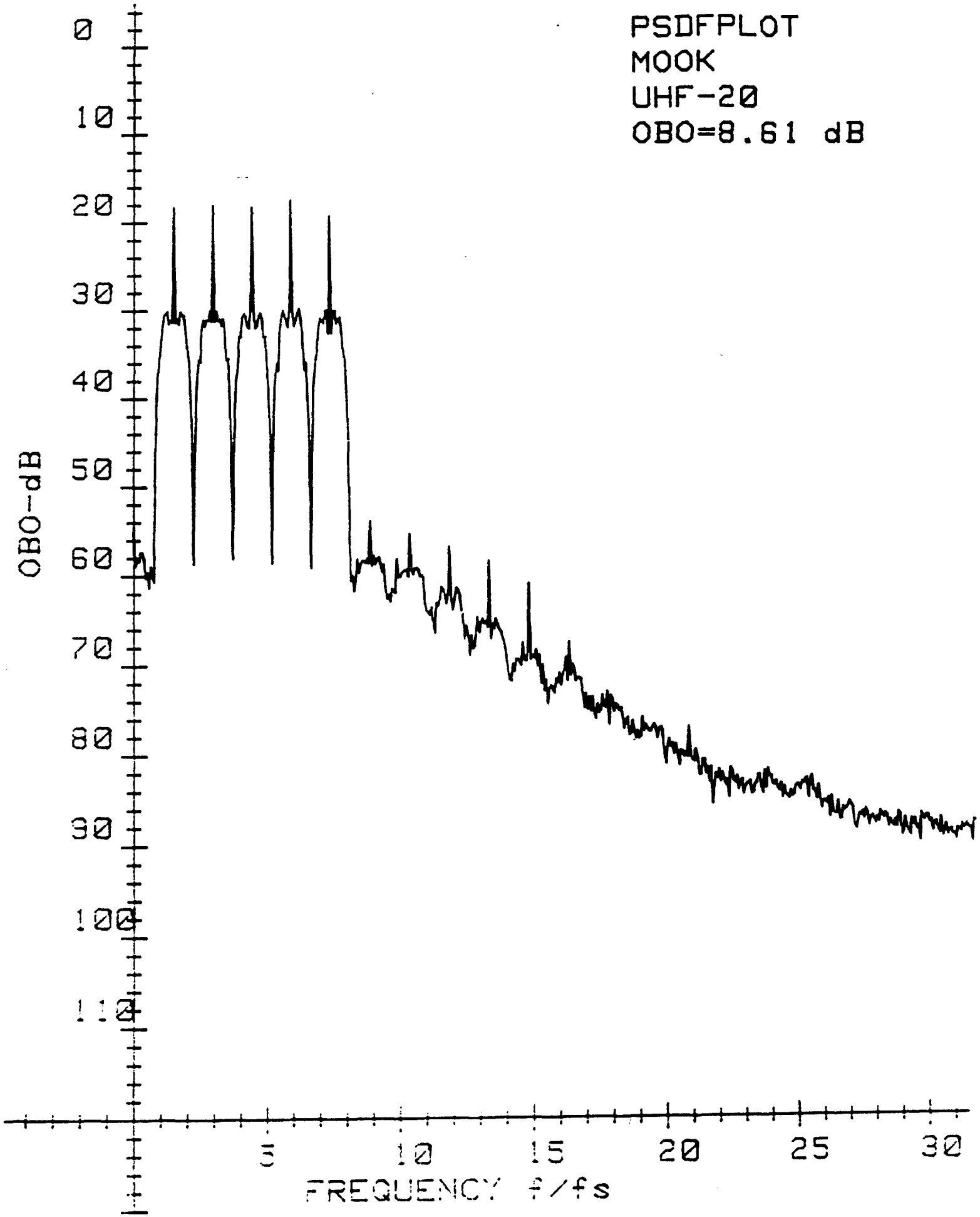
PSDFPLOT
MOOK
UHF-20
OBO=8.61 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 7

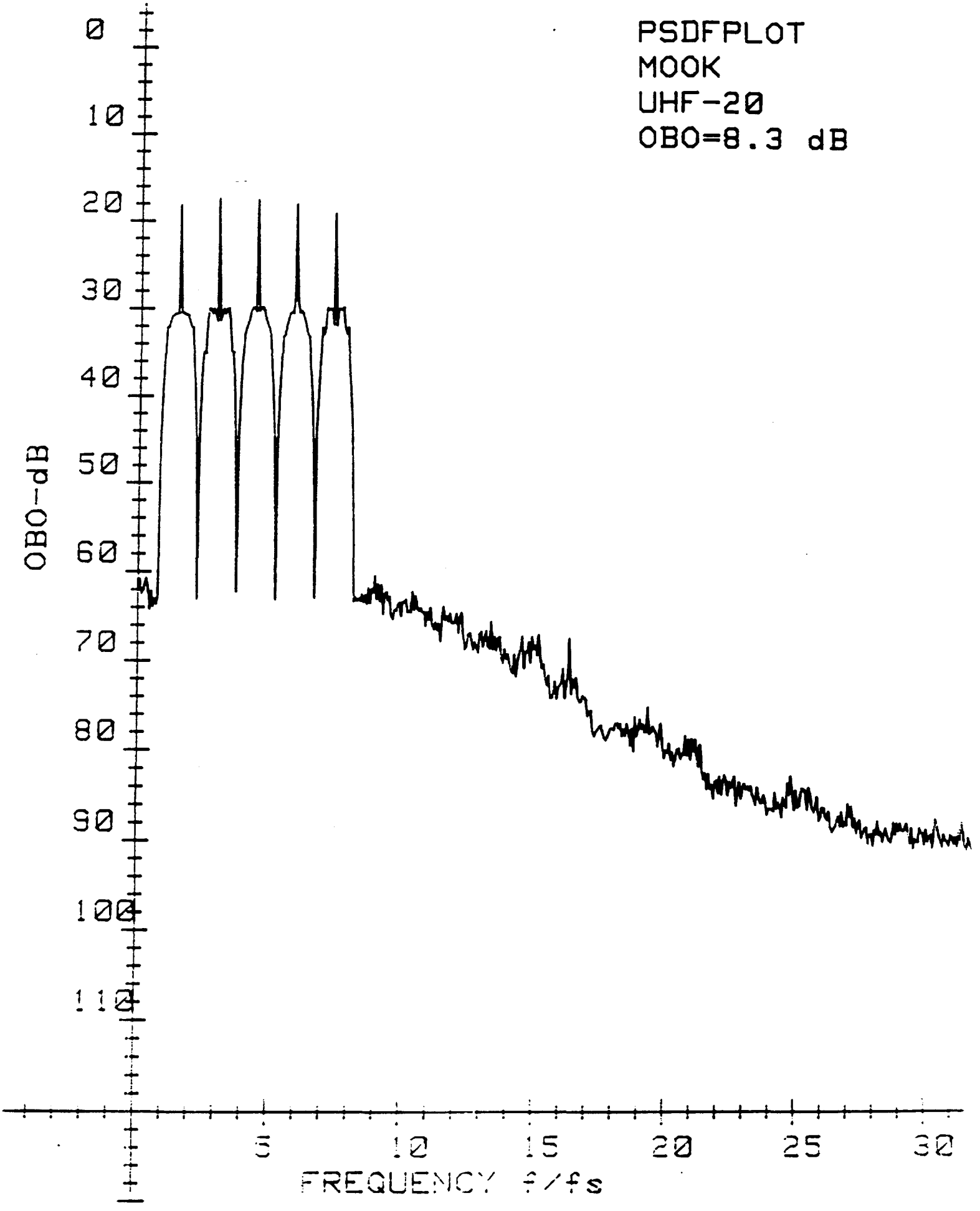
PSDFPLOT
MOOK
UHF-20
OBO=8.3 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 8

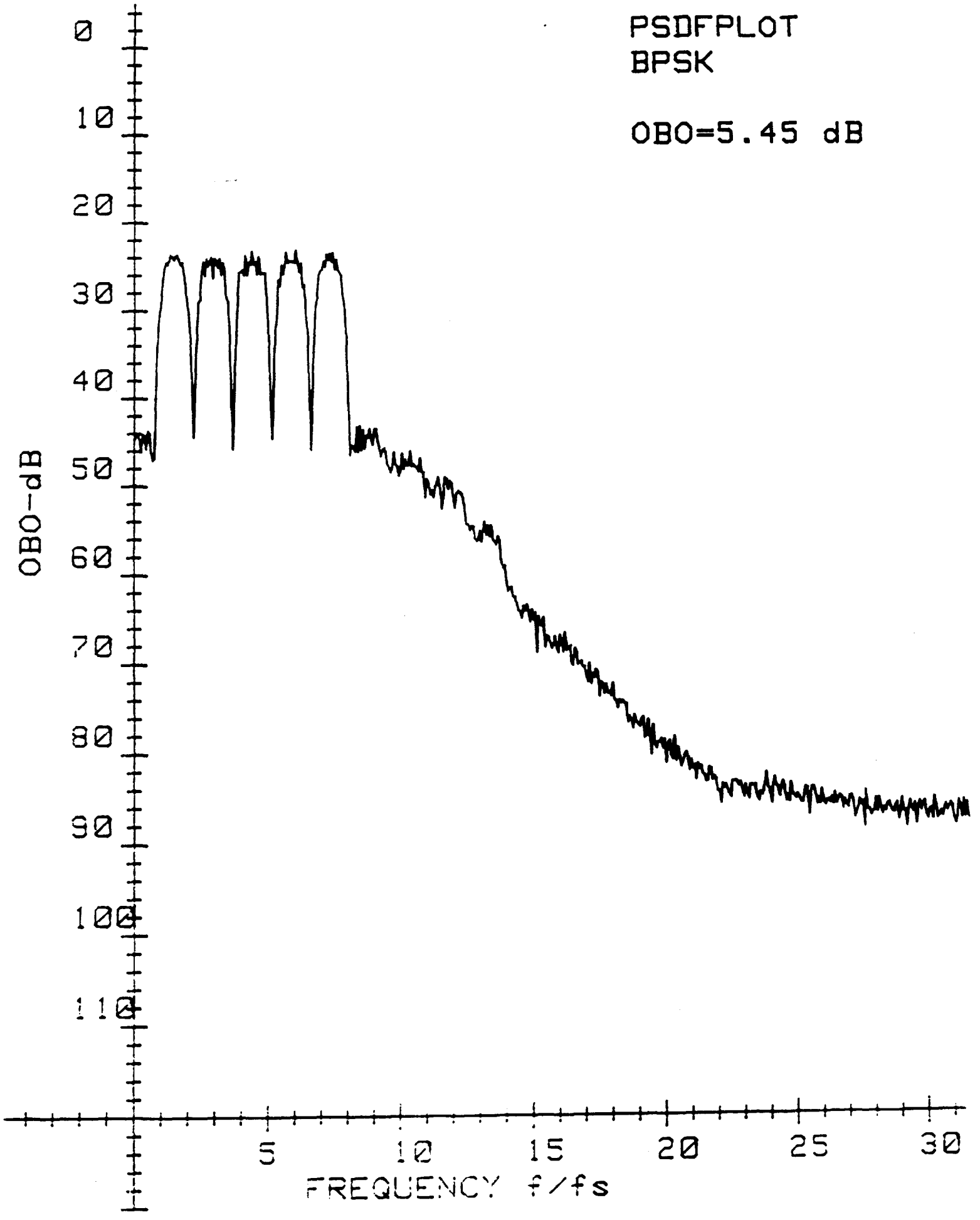
PSDFPLOT
BPSK
OBO=5.45 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 9

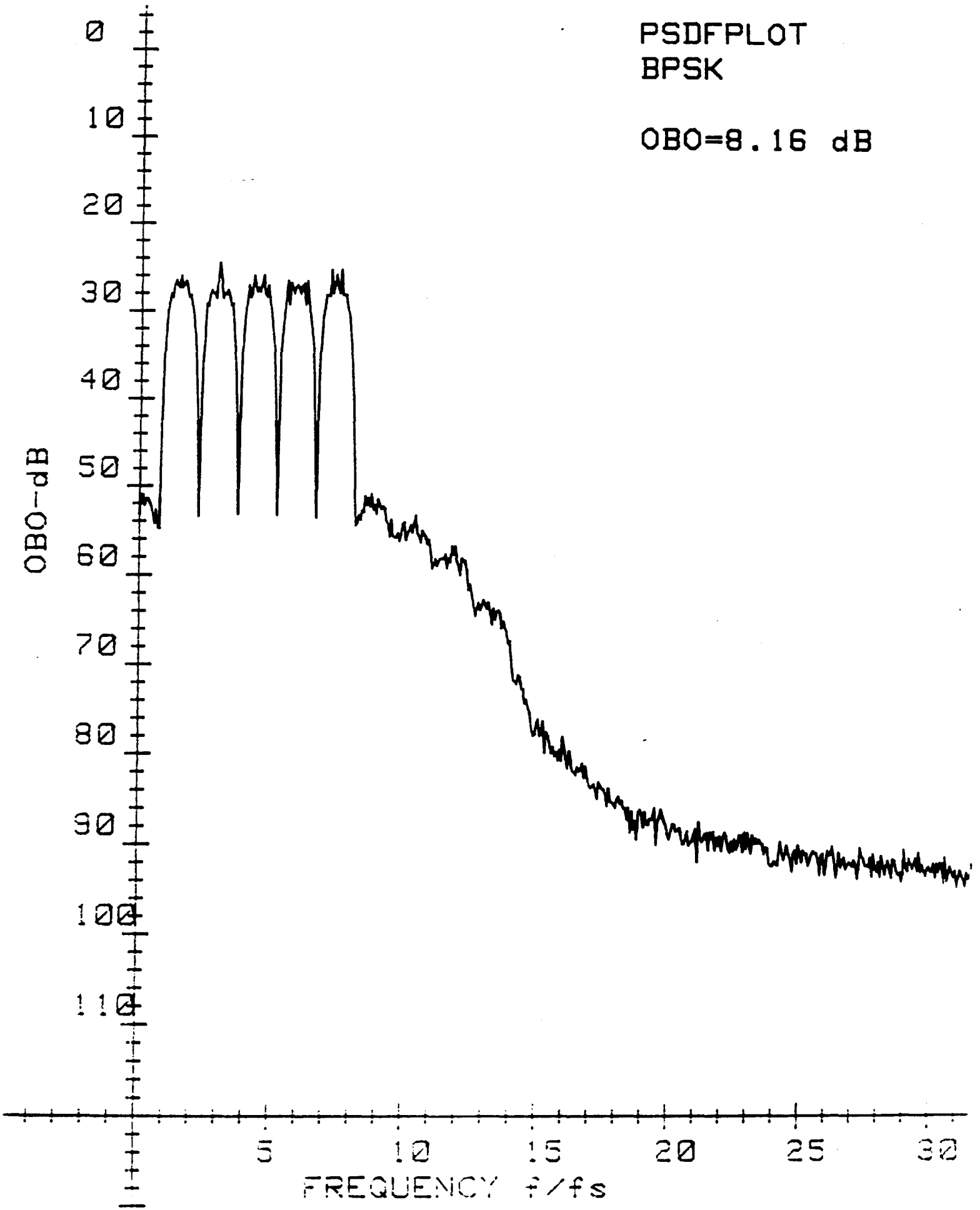
PSDFPLOT
BPSK
OBO=8.16 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 10

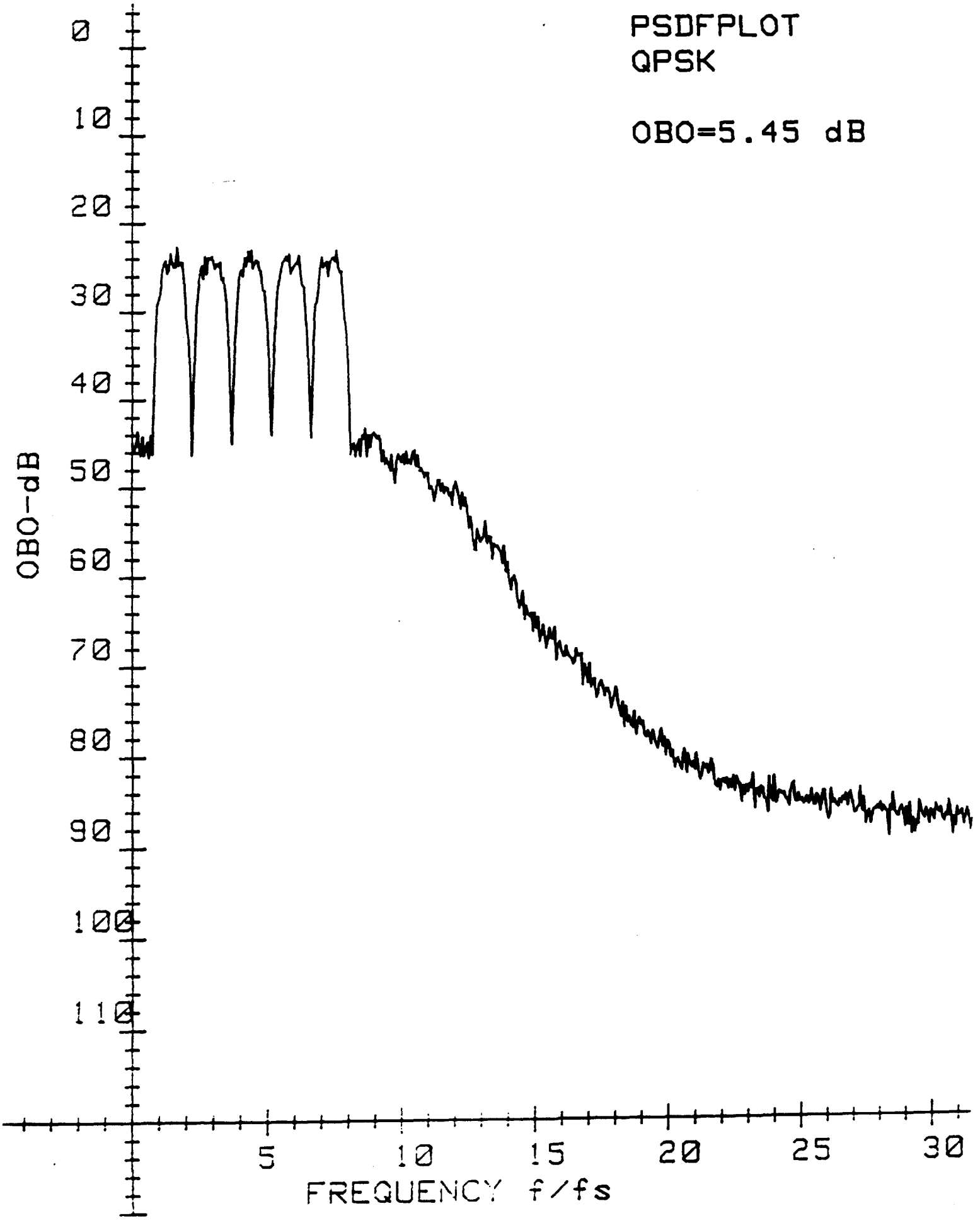
PSDFPLOT
QPSK
OBO=5.45 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 11

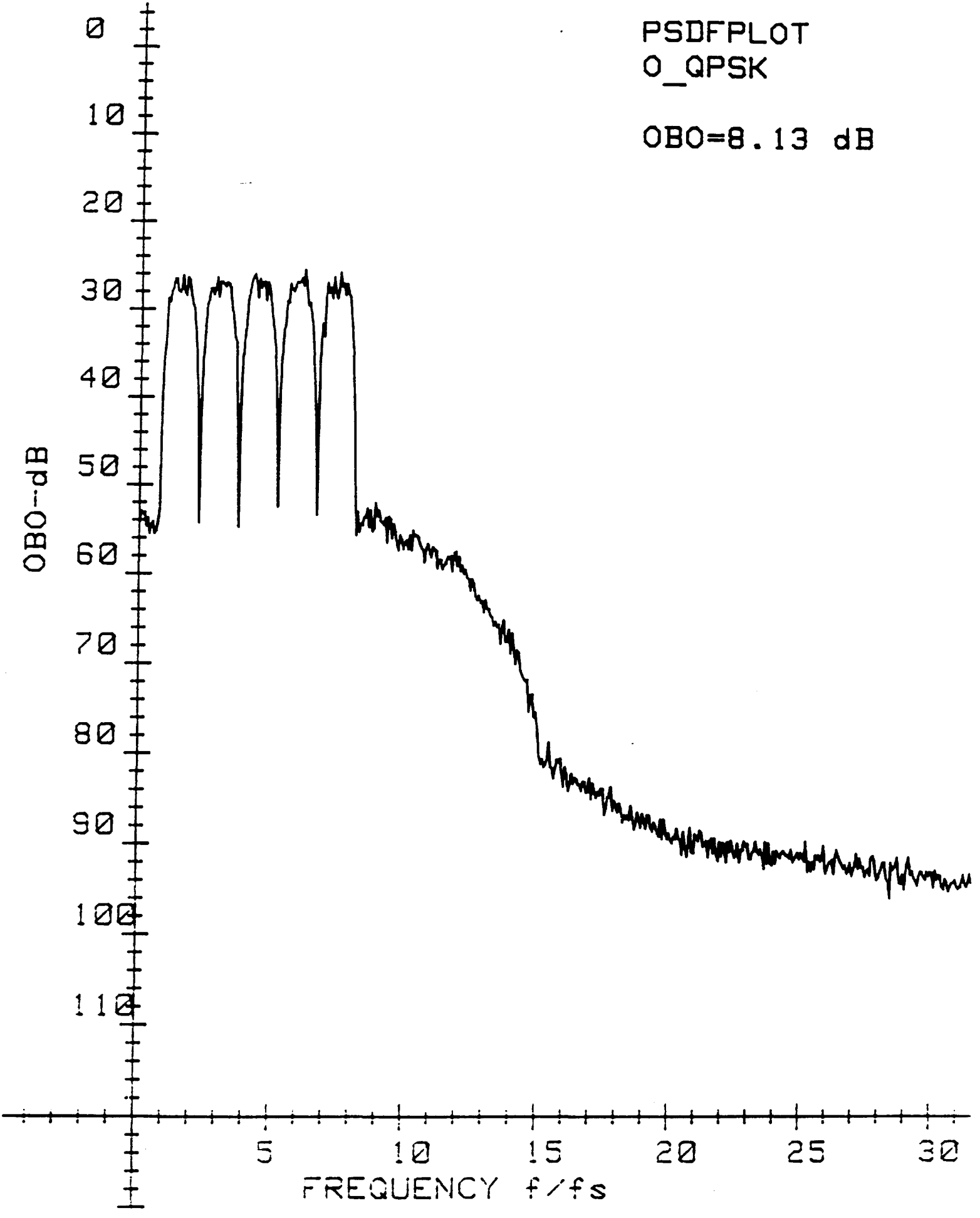
PSDFPLOT
O_QPSK
OBO=8.13 dB
OBO--dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 12

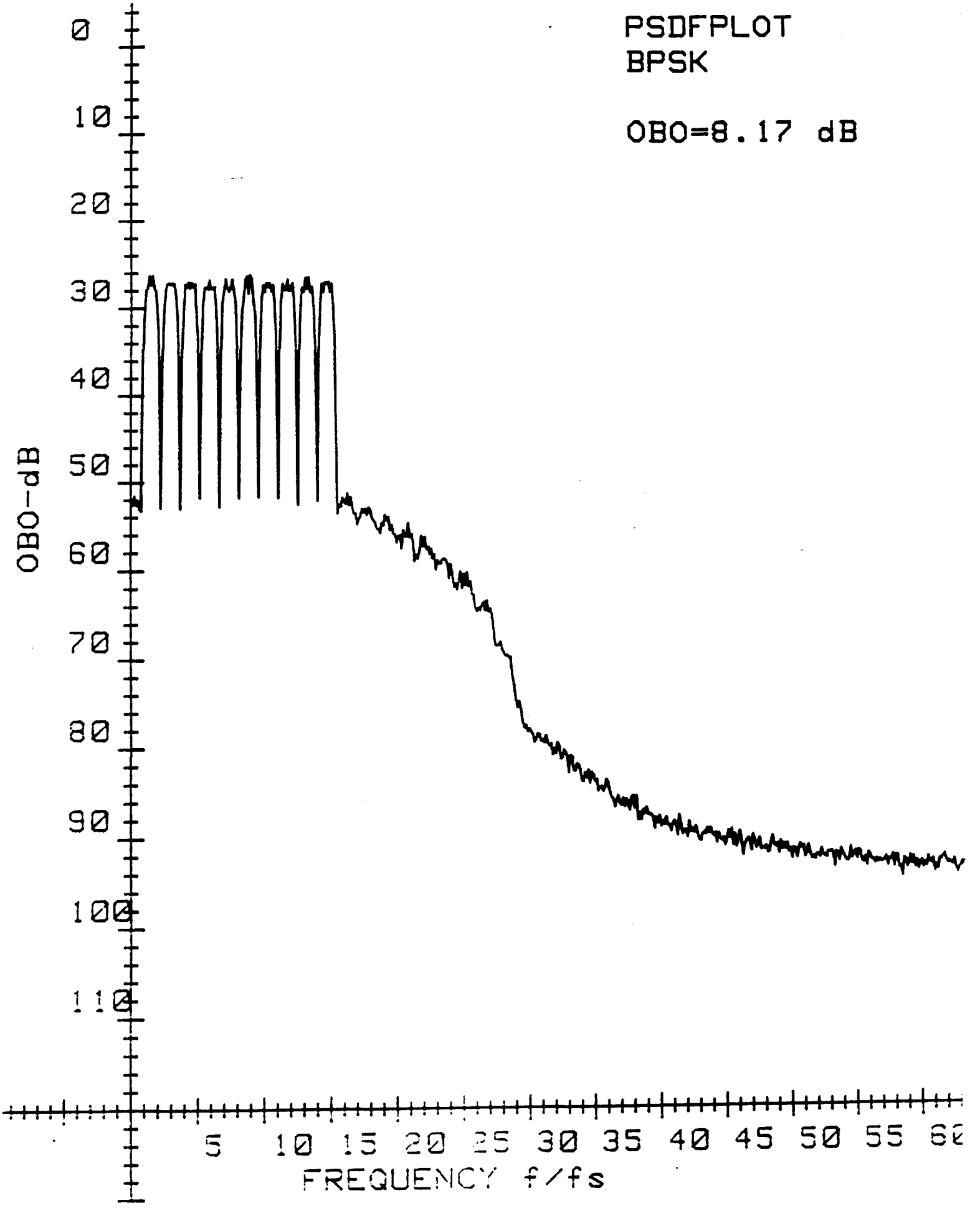
PSDFPLOT
BPSK
OBO=8.17 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
35
40
45
50
55
60
FREQUENCY f/fs

FIGURE 13

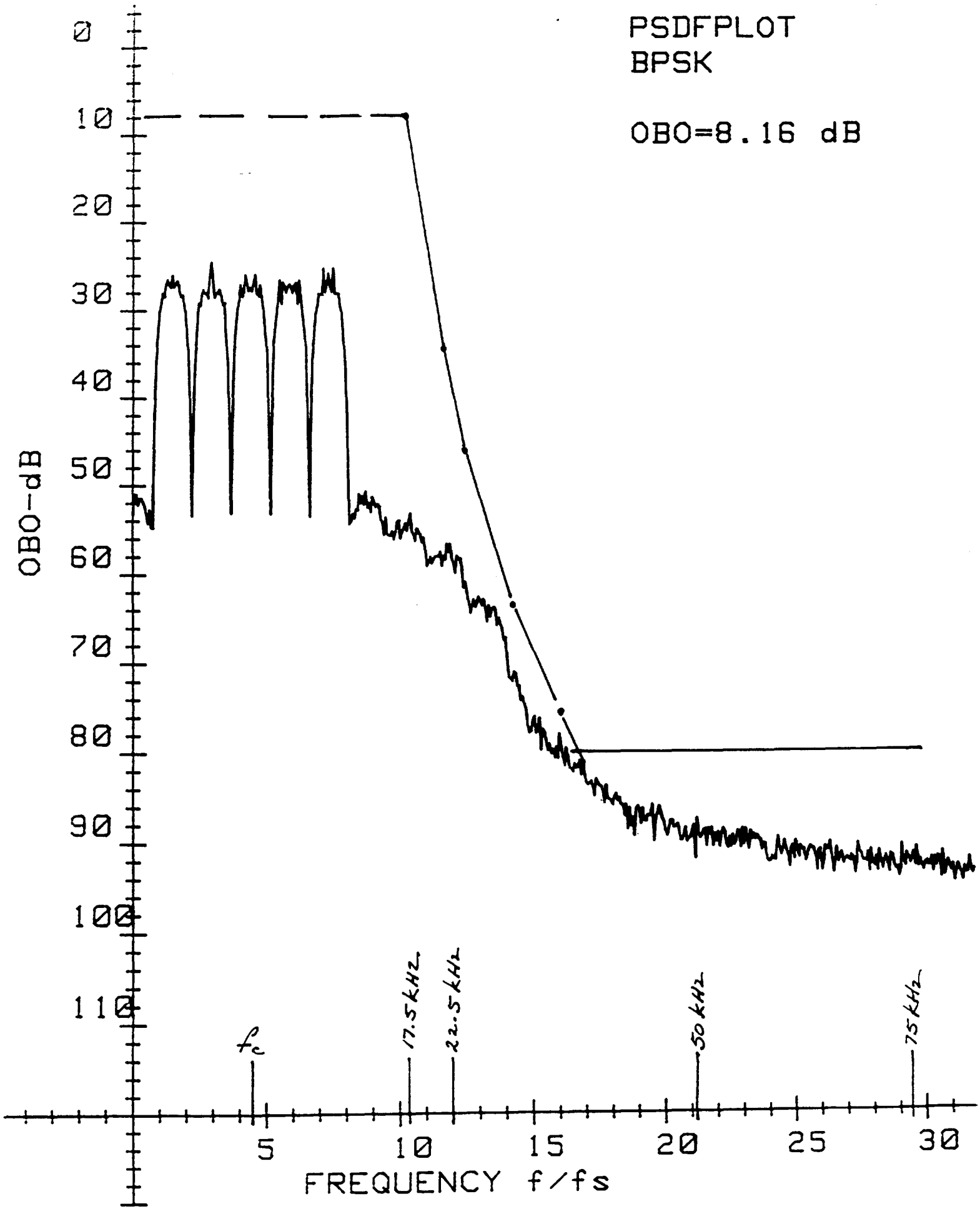
PSDFPLOT
BPSK
OBO=8.16 dB
OBO-dB
0
10
20
30
40
50
60
70
80
90
100
110
f_c
17.5 kHz
22.5 kHz
50 kHz
75 kHz
5
10
15
20
25
30
FREQUENCY f/fs

FIGURE 14

TAB B

Performance and Efficiency Considerations for the MTEL Nationwide Wireless Network (NWN) Protocol

R. Lukas, May 1992

MPR Teltech Ltd

TITLE: **Performance and Efficiency Considerations for the MTEL Nationwide Wireless Network (NWN) Protocol**

ABSTRACT: The radio link protocol proposed for the MTEL Nationwide Wireless Network is evaluated in terms of its efficient use of spectrum and performance relative to system design goals.

DOCUMENT NUMBER: TR92-1883
ISSUE NUMBER: Final Report
DATE: May 26, 1992

SUBMITTED TO: Mobile Telecommunications Technologies
P.O. Box 2409
Jackson, Mississippi 39225-2469
U.S.A.

CLIENT CONTACT: D. W. Cameron (601) 944-1300

MPR TELTECH CONTACT: N. Toms (604) 293-6104

AUTHOR:

Robert Lukas, P.Eng.
MPR Teltech Limited
Mobile Communication Solutions

MPR TELTECH LIMITED
8999 Nelson Way
Burnaby, BC
V5A 4B5

Table of Contents

1. EXECUTIVE SUMMARY 1

2. INTRODUCTION 3
   - 2.1. Purpose of the Document 3
   - 2.2. NWN Service Goals 3

3. ASSUMED TRAFFIC MODEL 5

4. DESCRIPTION OF THE LINK LAYER PROTOCOL 6
   - 4.1. System Architecture Description 6
   - 4.2. Protocol Format and Structure 6

5. PERFORMANCE EVALUATION 8
   - 5.1. National and Zonal Batching 8
   - 5.2. Cycle Header 9
     - 5.2.1. Cycle Synchronization 9
     - 5.2.2. Additional Synchronization Words 10
     - 5.2.3. Zonal Timing Offset 10
   - 5.3. Efficiency and Overhead 11
   - 5.4. Error Protection 12
   - 5.5. Message Throughput and Capacity 13
     - 5.5.1. Case 1: Perfect Channel, Outbound only with ACKs 13
     - 5.5.2. Case 2: Inbound and Outbound Load as per Traffic Model 15
   - 5.6. Delay - Outbound and Inbound 17
   - 5.7. Messaging Rates and System Capacity 18
   - 5.8. Portable Power Consumption 18
   - 5.9. Network Layer Protocol Considerations 19

List of Tables

Table 1: Mtel NWN Traffic Model 5
Table 2: Forward Channel Message Size Distribution 5
Table 3: Sync Word Performance 10
Table 4: Message Efficiency and Overhead Factors 12
Table 5: Error Correction Code Performance 13
Table 6: Forward Channel Capacity 14
Table 7: Duplex Channel Capacity 16
Table 8: Nationwide System Capacity 18

1. EXECUTIVE SUMMARY

This report has examined the encoding formats and elements of procedure of a link layer protocol intended for operation in a 2-way Nationwide Wireless Network (NWN) service. The protocol has been found to support the targeted subscriber population size and proposed traffic model in an efficient manner, with an adaptive response to traffic load and allowing a gradual evolution of network functionality. The primary protocol features promoting efficient use of the spectrum are:

- **Adaptive Zoning**: The number and size of zones can be dynamically altered according to overall traffic demand.
- **Zonal Independence:** Batching of messages and scheduling of forward to reverse channel time can be varied independently in each zone, allowing optimization to local traffic demands.
- **Dynamic Location Registration:** Relative location determination of each subscriber allows the network to schedule messages to the minimum number of zones, permitting a large degree of capacity reuse. Registration occurs automatically on receipt on any transmission from a portable, reducing or eliminating the need for separate registration message traffic.
- **Protocol Encoding Formats:** The protocol encoding formats chosen represent a reasonable tradeoff between the conflicting demands of overhead, robustness, portable processing capability, throughput and capacity.
- **Retransmission Protocol:** Positive confirmation of receipt and retransmission in case of errors leads to a high degree of reliability in the network. Retransmitting only when required allows a more efficient message encoding format to be used on the channel.
- **Scheduled Reverse Channel Access:** Solicited responses are guaranteed access to the reverse channel in scheduled manner that prevents collisions between portable transmissions. The ALOHA-reservation protocol allows a high degree of utilization of the reverse channel, particularly when the average message size is long in comparison to a reservation request. The protocol reduces the probability of media access collisions between portables and increases overall capacity and throughput.
- **Reverse Channel Contention Interval:** A short random-access reverse channel contention interval provides a simple but powerful media access technique.
- **Data Link Transparency:** Transparency in the data link allows the application to choose the most efficient manner of encoding messages. Multiple character sets or alphabets are possible; this allows higher layer data compression, increasing overall capacity.
- **Variable Length Batches:** Fixed system overhead is very small; no padding or otherwise unusable codewords are required.
- **Variable Length Messages:** Messages can be of any length. There is no lost capacity due to padding messages to integral block lengths.

- **Open-ended, Evolvable Architecture:** Advances and improvements in network processing in the areas of scheduling, zoning and batching algorithms can be made without change to the portable device. Capacity can be increased over time in response to traffic demand, independently for forward and reverse channel traffic.

The relevant performance parameters for the assumed traffic model are:

- Network Size: In order to support 600,000-800,000 subscribers, the network must be subdivided into 22-55 zones, depending on assumed traffic parameters, for a 13% busy hour call rate.
- Message Rate per Zone: The maximum message rate per zone varies from 1872-3432 messages per hour, depending on message success rate, and forward:reverse traffic ratio, for an average message size distribution of 3000 characters outbound and 400 characters inbound.
- Overhead: Fixed system overhead is less than 1%. The average encoding efficiency is between 65 to 95%, depending on message length and coding format. Reverse channel acknowledgments do not appreciably affect the overall encoding efficiency when considered as overhead.
- Average Delay: Transmission delay through the network will average three minutes for messages segmented into multiple packets. A typical transaction will be complete in less than five minutes.
- Portable Battery Economy: Idling portable devices require only a 0.28% duty cycle to maintain synchronization with the network.

2. INTRODUCTION

2.1. Purpose of the Document

This study addresses the Mtel request to determine the efficiency of spectrum usage of a radio link protocol consistent with general scheme proposed in Mtel's petition for rulemaking for a 2-way Nationwide Wireless Network (NWN) Service in the 930 MHz frequency band. The analysis, conclusions and recommendations are developed within the framework of the system's proposed service goals and the physical constraints of a portable terminal device.

The analysis evaluates the protocol design choices against the system performance and service goals and provides supporting arguments for those design choices. Where relevant, alternate strategies that may improve performance are noted and areas of possible concern are highlighted and suggested for further investigation.

The performance, capacity, throughput and efficiency of the protocol are estimated for expected traffic models and claims of performance are validated against standard paging protocols, such as POCSAG and ERMES.

This report does not consider the effects of the proposed modulation or wide-area simulcast techniques. The estimated performance of the modulation and simulcast techniques is the subject of a separate report prepared by MPR Teltech Limited. For the purposes of this report, it is assumed the modulation and simulcast techniques will provide the claimed performance.

2.2. NWN Service Goals

As Mtel has noted in its petition for rulemaking, there is no single spectrum efficient technology. The most appropriate technique depends on the problem to be solved. Therefore, we review the goals of grade of service and expected modes of operation of the NWN as a framework in which to evaluate the proposed radio link protocol. These service goals and operational modes are distinctively different from the "normal" one-way paging services presently offered:

- **Two-way Messaging Service:** the primary mode of operation is expected to be two-way messaging, providing the customer with the ability to originate as well as respond to messages. Current paging protocols such as POCSAG and ERMES do not address this requirement. The system will also support one-way paging.
- **Email-like Applications:** the average message length is expected to be significantly longer than that seen in numeric or alphanumeric paging services, although the architecture facilitates efficient transmission of short messages as well. Email-like applications are expected to be the dominant use of NWN services.
- **Positive Acknowledgment of Receipt:** Through the use of reverse channel acknowledgments, the NWN service will be able to give positive confirmation of correct message delivery to the message originator, and provide higher reliability of message delivery through retransmission in case of errors. It will also allow the NWN to offer as an option a premium grade of service where messages are held until deliverable.

- **Significant Reverse Channel Message Traffic:** Reverse channel traffic is not expected to be limited only to "ACK-back" pager operation. Portable devices will respond with preformatted short answers ("Answer-back" operation) as well as portable-initiated requests for data, and longer messages composed on notebook or palmtop computers, initiated at random times.
- **Application Independent and Transparent:** The basic radio link protocol does not impose any constraints of data content or format on subscriber applications.
- **Expandable Wide Area Coverage:** The NWN service will be a nationwide system with wide area coverage of metropolitan areas and providing in-building penetration. Messages will be successfully delivered to portables moving at pedestrian and vehicular speeds.
- **Geographic Location Determination:** The location of any particular subscriber can be determined automatically nationwide to a relative geographic area.
- **Portable User Terminals:** A user device resembling a notebook computer or palmtop portable device in size, weight, display, keyboard and computing capacity with integral radio modem is assumed.
- **High Capacity, High Speed Operation:** The NWN service will operate at raw bit rates of 18-24,000 bps on the forward channel, significantly faster than any other paging service. As a result of the high speed and system network architecture, the NWN will support a high number of subscribers, even though message lengths are much longer than standard paging systems. Capacity can be expanded in a graceful, evolutionary way through capacity re-use in an incremental fashion.

As evident from the above service goals, the NWN will offer a premium grade of service over standard paging.

3. ASSUMED TRAFFIC MODEL

The performance estimation is derived by considering a traffic model and overall system architecture consistent with the above service goals. This traffic model has been developed by Mtel as a preliminary estimate and needs to be verified by experimental operation and market research data.

Parameter	Value
Average Message Size: Forward channel Reverse channel	 3000 bytes 400 bytes
Channel Bit Rate: Forward Channel Reverse Channel	 24000 bps 9600 bps
Traffic Distribution: National coverage Zonal coverage	 5% 95%
Busy Hour Call Rate	13%

Table 1: Mtel NWN Traffic Model

The average message size was derived from an estimated distribution of messages as shown below. We assume an equivalently scaled distribution would apply to the reverse channel message traffic.

Message Size	Distribution
10,000	15%
5,000	15%
2,500	25%
1,000	15%
500	15%
80	10%
≤40	5%
3000	average

Table 2: Forward Channel Message Size Distribution

Note that no traffic model for message success rate has been provided. This data is still being researched by Mtel, based on market/customer use factors such as the expected percentage of devices turned off, as well as technical factors such as the required RF signal strength for the desired coverage areas. As a reference point, other data-over-radio protocols, such as ARDIS, are generally designed for 95% or better success rate, assuming in-range, enabled devices.

4. DESCRIPTION OF THE LINK LAYER PROTOCOL

A general description of the protocol being considered is given below. The protocol has been revised and improved somewhat from the original protocol described in the petition for rulemaking submitted in November 1991.

4.1. System Architecture Description

The system architecture is one based on nationwide simulcasting, using a single simplex channel. The forward (base to portable) and reverse (portable to base) transmissions share the single channel using a dynamic time division duplexing scheme to accommodate variable demand in forward and reverse channel directions. In addition to all stations and subscribers being synchronized and locked to a common nationwide transmission cycle, the forward channel can be subdivided into zones to increase capacity re-use. Each forward channel zone will transmit messages destined only for portables known to be located in the zone, eliminating useless and wasteful transmissions in unneeded coverage areas. Where a portable's location is unknown, or is known to be in a simulcast overlap/interference area between zones, the message will be transmitted in the nationwide simulcast portion of the cycle.

Because the portable device transmitter is significantly lower power than the base station transmitters, the base station receiver network will be more extensive than the transmission network to achieve the same coverage. The aggregate reverse channel capacity from all NWN receivers is greater than the forward channel, permitting lower bit rates and simpler modulation scheme to be used to balance the inbound and outbound capacity. The base station receiver network and receiver coverage areas can be designed independently from the transmission network and receiver service areas will be significantly smaller than forward channel zones. This will permit multiple receivers per zone to be active in the reverse channel part of the cycle.

4.2. Protocol Format and Structure

The NWN link layer protocol is time division duplex, organized within cycles of 30 seconds duration. Within each cycle, a number of fields are defined. Each field, with the exception of the Cycle Header, is variable in length, dependant on traffic requirements.

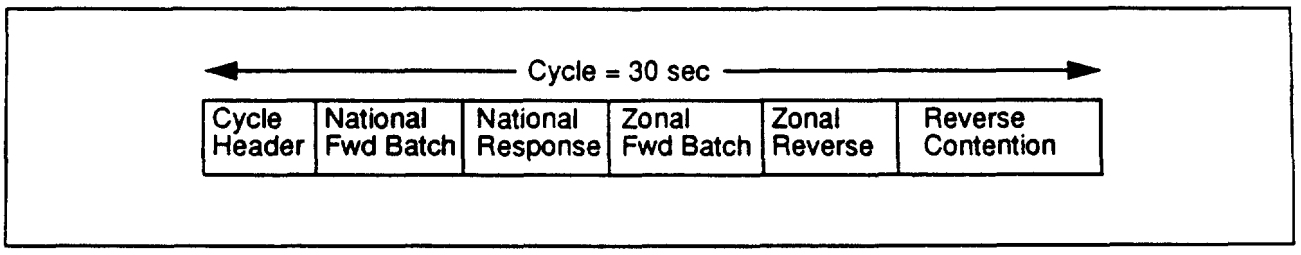

Figure 1. Link Layer Protocol Structure

Within each cycle, the quantity of time allocated to forward or reverse channel is set dynamically to compensate for variations in traffic loading.

During the zonal forward portion, each zone transmits messages unique to its zone, which will be the majority of its traffic. The above structure permits each zone to independently vary the propor-

tion of forward:reverse time allocations, corresponding to the demand present in each zone. This structure is a significant improvement over the original protocol, which selected forward:reverse allocations on a national basis.

During the forward batch intervals, the portable address space is segmented into 64 groups, with each group's batch consisting of a header scheduling the forward channel messages and allocating reverse channel time to each portable as required. The batch structure permits considerable power savings within the portable device by permitting the device to only power up at precisely scheduled short intervals to check for the presence of a message addressed to it, and again only during the actual message transmission period. The encoding scheme also allows an address group with no traffic on any particular cycle to have its batch eliminated from the cycle and occupy zero forward channel time.

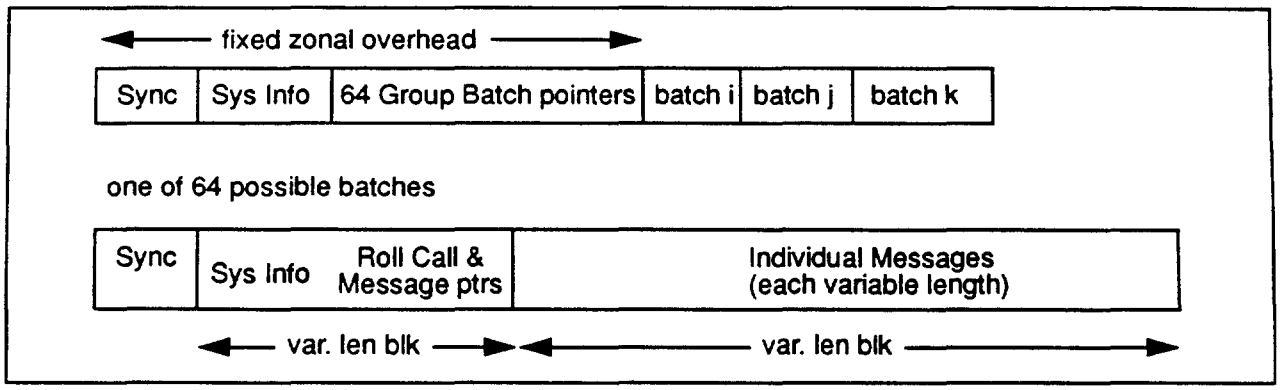

Figure 2. Forward Channel Header and Batch Structure

The reverse channel is further subdivided into two intervals: (1) national and zonal deterministic intervals when portable responses are precisely scheduled, and (2) contention interval when any portable can initiate communications. Since the relative location of most portables is known, reverse channel time can be assigned simultaneously to a number of portables by examining mutually exclusive lists of receivers, such that no data collisions will occur at any network receiver. The contention interval is required to eliminate wasteful polling of portables, and is used to allow a portable to request the allocation of reverse channel time in the deterministic interval. Slotted-ALOHA is used to access the channel during the contention interval.

5. PERFORMANCE EVALUATION

This section evaluates the performance of the protocol in relation to its efficiency, throughput, capacity for the proposed encoding format and the assumed traffic model.

5.1. National and Zonal Batching

The proposed protocol greatly facilitates a high degree of capacity re-use in both the forward and reverse channel, variable load conditions and as well as a high degree of freedom in planning incremental network expansion to meet subscriber demand.

With respect to capacity re-use, the network can be subdivided in zones of size matching the local geographic service demand. Base transmitters will be grouped into zones, where each zone transmits traffic only destined for its service area. Zonal subdivision can be done either statically, resulting in less complex scheduling and batching algorithms, or can be dynamically adjusted during the day on a cycle by cycle basis. The zonal subdivisions are transparent to the portable device.

Zonal subdividing will create interference areas, however, where the coverage areas of two zones overlap. With a small number of zones, the interference areas will be minimal, and with proper network coverage planning, zonal interference areas can be designed to occur in less populated areas, for example, between urban areas. However, for those portables that happen to located in an interference area, the network will transmit those messages during the nationwide simulcast portion of the cycle.

The zonal subdivision structure of the protocol therefore gives the network the ability to increase capacity on demand, resulting in a high degree of efficiency when considered on a national scale.

As the sizes of zones decrease in response to increased traffic demand, the number of portables located in interference zones will increase. One technique that may be employed if the traffic in the nationwide simulcast portion is too high is dithering of zones, in effect, changing zone structure from cycle to cycle, resulting in the portables who may be in an interference area in one cycle being in a clear area the next. This optimization technique only affects the network scheduling algorithm and could be implemented transparently to the portables.

Zoned transmission techniques will only be effective as long as the network has an accurate idea of the relative location of each portable device. There are many strategies available to maintain this network database. The most optimal choice may depend on particular customer demographic profiles, considering the degree and frequency of mobility, the call rate, message success rate and overall network load.

The protocol facilitates location determination by permitting any reverse channel transmission (including acknowledgments, reservation requests and portable-originated messages) to serve as a form of registration. This eliminates the need to poll devices on a periodic basis, or the need to transmit periodic location registration messages. However, the zone identification is transmitted in every cycle header, such that a portable can easily determine when it has moved, and transmit a registration message only when required. Alternatively, the network can search for a lost portable by soliciting a short response during the nationwide simulcast portion of the cycle.

The protocol structure also handles local variation in traffic patterns. Each zone can independently schedule the proportion of forward to reverse channel traffic. This optimizes the utilization of the channel, and offers better overall throughput.

The combination of adaptive zoning, location determination, nationwide simulcasting and zonal independence features in the protocol therefore promote an efficient, high-throughput service that can adapt to local variations in demand and provide open-ended growth in capacity.

5.2. Cycle Header

The cycle header consists of preamble for symbol synchronization, the frame synchronization word and fixed system overhead announcing the forward channel offset for the zonal portion of the cycle. Accurate cycle synchronization and determination of the timing of the zone batches is critical to the operation of the network. The timing reference is specified relative to the end of the cycle sync word and measured in units of forward channel symbols (bauds). The multitone modulation scheme being considered transmits 3000 baud, which works out to 90,000 symbols/cycle, requiring timing offsets to be specified as 17 bit quantities.

It is appropriate to examine the performance of the chosen sync word and error protection of the remaining cycle header, since failure of either will destroy the cycle.

5.2.1. Cycle Synchronization

The cycle synchronization codeword is a unique word which is used to identify the start of the frame. The frame sync word is specified is the 32 bit codeword 7CD21518H. Portable receivers will detect synchronization by an auto-correlation operation on the received data and the reference word. The auto-correlation function for the chosen sync word is shown below.

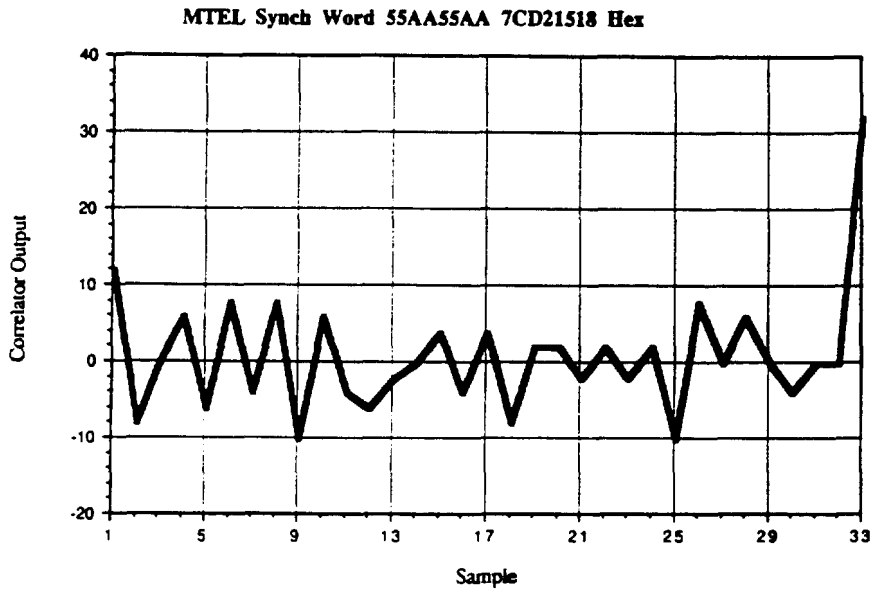

Figure 3. Mtel Frame Sync Word Correlation Function

This sync word shows excellent low sidelobes in the auto-correlation. In order to improve the performance in the presence of noise-induced receive errors, binary correlation with threshold detection is normally employed. Table 3 shows the performance of this sync word for the probability of missed synchronization or false synchronization for different bit error thresholds in the presence of BER 10^{-2} channel.

The table shows that a reasonable error threshold may be 8 errors in the sync interval.

Error Threshold	P(missed sync)	P(false sync)
4	1.61×10^{-6}	9.6×10^{-6}
8	2.27×10^{-11}	3.5×10^{-3}
10	1.0×10^{-14}	2.5×10^{-2}

Table 3: Sync Word Performance

5.2.2. Additional Synchronization Words

The protocol has specified additional synchronization words to be used to identify the beginning of zonal batch subframes, but has not identified the codeword used. The codeword used for cycle synchronization must be unique, in order that a portable which has just been turned on can scan for and lock to the cycle header. An appropriate batch header sync word is the inverse of the cycle sync word. The same synchronization word can be used for each batch header, since batches are separated in time, and the portable has an accurate idea of the position of the batch header in the cycle. As well, the batch header contains information identifying the batch number.

5.2.3. Zonal Timing Offset

The timing offset to the beginning of the zonal forward header is specified as being carried in a BCH(31,21) codeword with an additional parity bit. Note that this code, while being simple to decode, has the properties of correcting any two bit errors and detecting any three. Maximum burst error detection is 11 bits. Given the importance of error-free reception of this particular codeword, consideration should be given to improving its protection. One simple technique that is already used in the rest of the protocol is interleaving the codewords on a 24:1 interleave. An effective technique would be to interleave the zonal offset codeword with the fixed length national header codeblocks as originally specified. This would protect the zonal timing offset information such that a burst error of up to 96 bits in length could be corrected.

The composition of the cycle header therefore provides a high degree of robustness in the presence of errors due to noise on the channel, with consequent high reliability, probability of successful message reception and overall throughput.

5.3. Efficiency and Overhead

The efficiency of the protocol is a combination of many interrelated factors. There is a certain amount of fixed system overhead introduced per cycle for cycle headers, batch headers, and a variable amount based on number of messages, and message encoding efficiency. For the proposed NWN protocol, these overheads are summarized below:

T_{CH} = 38 msec	Cycle Header overhead of Base Transmitter turn-on time, preamble and frame sync word, cycle timing words
T_{NH} = 64 msec	Fixed overhead portion of the National Forward Channel Batch (2 codeblocks
T_{ZH} = 98 msec	Fixed overhead portion of the Zonal Forward Channel Batch (3 codeblocks)
T_{fixed} = 200 msec	Total fixed overhead per 30 second cycle (0.7%)

Messages are transmitted in variable length batches. The messages in each batch are called out by an integral number of header code blocks containing the address roll-call and timing offsets for forward channel messages and allocated reverse channel slots for acknowledgments. The encoding scheme would allow packing of ten message and acknowledge schedules per block. The overhead introduced by the address header blocks is thus a function of number of messages transmitted per cycle. Each address header block is 34 msec long, effectively 3.4 msec per message.

Messages themselves can be variable length. Two encoding formats are under consideration, (1) FEC protected blocks of 24 codewords, efficiency 66% and (2) CRC-only protected variable length messages, efficiency greater than 95%, depending on length. The tradeoff of CRC versus FEC will depend on the expected message success rate, and the number of retransmissions that can be tolerated. We expect that if CRC encoding is employed, long messages will still be segmented into smaller packets, with packet-level retransmissions rather than message-level retransmissions in order to improve the message success rate. A suitable packet size may be in the range of 128 bytes. Long messages for a portable would transmit multiple packets in a single cycle, and expect an acknowledgment once per cycle.

The transmission of reverse channel acknowledgments also can be considered a form of overhead, due to the time-division duplexing of the simplex channel. Reverse channel acknowledgments reduce the time available to transmit forward channel messages. The exact reverse channel encoding is still under consideration. One format under consideration calculates an acknowledgment as 5.3 msec duration. We suggest a format in section 5.6 that eases timing constraints on the portable that requires 11 msec per acknowledgment.

Because reverse channel time allocation directly affects the throughput of the forward channel, the design of the base receiver network for capacity re-use is a factor in calculating throughput and efficiency. Conservative estimates of talk-in range versus total zone coverage area would project a reverse channel capacity re-use factor within each zone of at least 1.5.