IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: **Proposal for a Channelization Scheme for the Direct Sequence Spread Spectrum PHY**

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Abstract:

Given over 80 MHz of available bandwidth in the 2.4 GHz ISM band, a channelization scheme is possible to maximize re-use of bandwidth and also provide the most flexibility in avoiding tone and narrow band interferers.

The DSSS PHY standard must specify channel parameters to assure inter-operability. There are four parameters that can be varied to create a unique channel. These are: centre frequency, chip rate, code length, and modulation (DPSK, QPSK, etc.). A group of such channels can be called a "channel set".

This paper proposes several possible channel sets, some of which would be mandatory for compliance and some optional. The definition of a range of channel sets can address the often contradictory requirements of different applications of wireless LANs.

The issues discussed concern the channel-to-channel isolation of a channel set, and the constraints that must be put on the transmit spectrum to achieve it.

1.0 Introduction

In 802.11, the concept of an Extended Service Set (ESS) consisting of multiple Basic Service Sets (BSSs) has been defined. The intent of such a system is to provide wireless coverage for an arbitrary environment. Each station (STA) in the ESS should expect a certain level of performance (i.e. throughput) to be maintained as more and more users become active throughout the ESS. Several factors work against this expectation, such as, overlapping BSSs, overlapping or neighboring ESSs, and jamming from dissimilar systems. All of these factors have the effect of forcing the STAs and Access Points (APs) to share the available radio bandwidth with other systems.

In a ESS consisting of DSSS STAs and APs, it is the function of the "channel set" to minimize the inter-BSS interference and maximize the available bit rate. Given the four parameters: centre frequency, chip rate, code length, and modulation type, it is possible to define many different channel sets for a DSSS PHY. The merit of a channel set is determined both by the bit rate and by the isolation that can be achieved between many overlapping BSSs.

Given that relatively short spreading code lengths are used (≤ 31), the amount of isolation obtained from processing gain alone (< 10 dB) is not sufficient to allow channels to be separated by code division. The only other means of obtaining channel isolation is to separate channels in frequency.

In DSSS with a minimum code length of 10 or 11 chips, there is a tradeoff between data rate and bandwidth, and therefore, the channel separation that can be obtained. It is this tradeoff and the channel sets derived from it that are discussed in this paper.

One assumption made is that channels within any given channel set use the same chip rate. This makes it easier when implementing a channel set since filtering requirements remain the same channel-to-channel. A node wishing to support multiple channel sets would have to modify or switch its shaping filters.

The main issue that arises from the discussion on channel separation using frequency division is the requirement to ensure the transmit spectrum of the DSSS PHY does not spill over into adjacent channels.

1.1 Spectrum Shaping of DSSS Transmitter

Co-channel interference stems directly from the nature of the spectrum shape output from a DSSS transmitter. The spectrum shape of an ideal spread spectrum transmitter is shown below. As can be seen there is a significant amount of energy in the side lobes, which will cause interference in adjacent channels of a channel set.

The amount of interference can be minimized by applying a filter to shape the output spectrum of a transmitter. The filter would reduce the level of the side lobes and part of the main lobe as can be seen in the figure 2.2. An implementation example will be described in a later section.

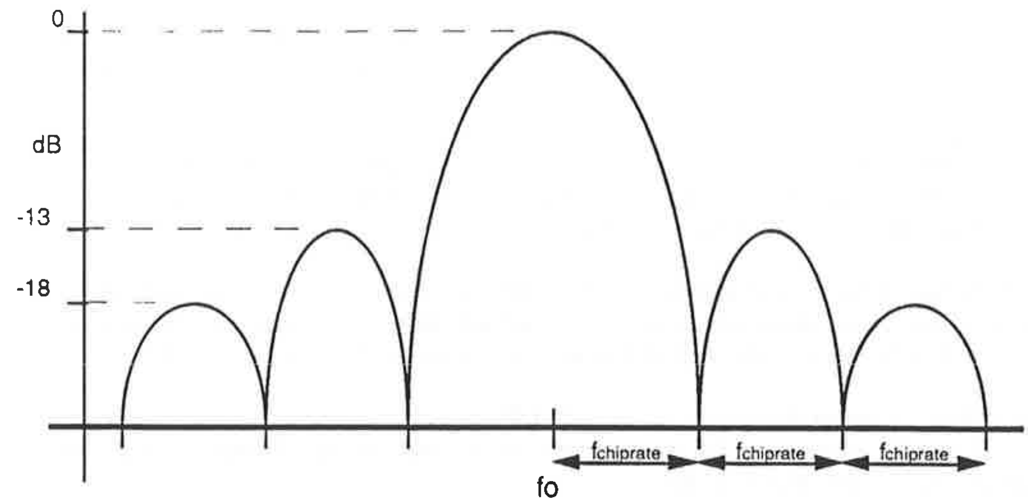


Fig. 1.1 Ideal Spread Spectrum Shape

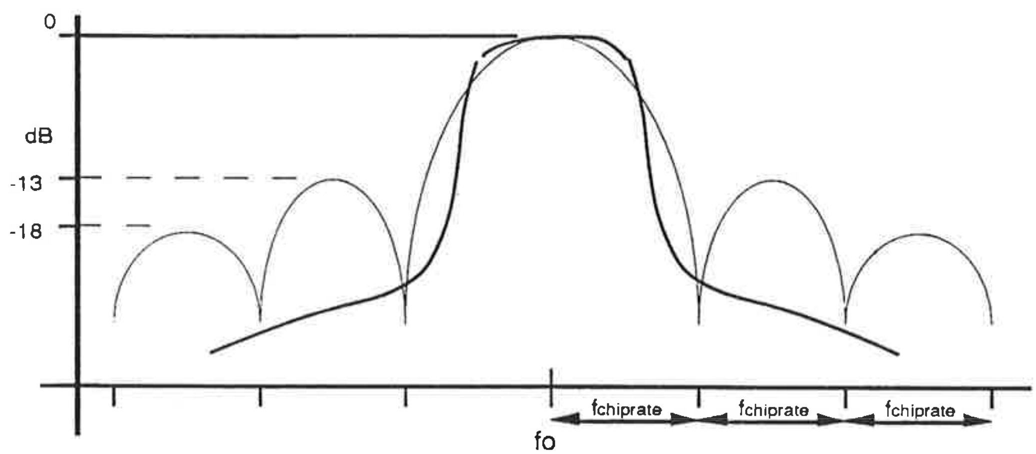


Fig. 1.2 Filtered Spread Spectrum Shape

The resulting spectrum shape transmits a reduced amount of energy in adjacent channels allowing channels to be placed closer together and thus giving more efficient use of the spectrum.

A system that utilizes lower chiprates will naturally use less bandwidth, therefore one tradeoff that will be shown is chip rate versus number of isolated channels.

1.2 Chip rate and Filter Bandwidths

The chip rate determines both the bandwidth of the main lobe of the transmit spectrum as well as the achievable bit rate. The bit rate can be determined by the following equation:

$$\text{Bit rate} = \frac{\text{chip rate} * \text{Modulation factor}}{\text{code length}}$$

The modulation factor is the number of bits per symbol. QPSK corresponds to a modulation factor of 2 and is the modulation of choice given the relative simplicity of its implementation.

The bandwidth of the TX shaping filter and the IF selectivity filter can be picked so spectrum use is minimized and selectivity is maximized. It has been found in practice that, since most of the energy in a spread spectrum signal is in the centre portion of the main lobe, link quality is not greatly affected by applying a filter with bandwidth less than twice the chip rate.

For example, an 11 Mchip/s baseband signal could be filtered using a 5.5 MHz Low Pass filter. Experimental results of such a system are shown in a later section. Similarly, in the receiver, the IF selectivity filter need only be as wide as half the main lobe or in this case 11 MHz.

The chip rate used affects a radio design in the bandwidth of the transmit shaping filter and also the required width of the IF selectivity filter. If lower chip rates are used then less spectrum is used but only if the filters are designed for this.

2.0 Channel Sets

A Channel Set is a group of channels occupying a number of centre frequencies. Each frequency contains a channel at the maximum data rate achievable for a given chip rate as well as fall back channels that use either lower modulation factors or longer spreading codes. Code lengths of 11 should be mandatory while optional lengths of 22 and 31 should also be defined.

The purpose of having multiple frequencies in the channel set is to allow avoidance of existing jammers as well as provide isolation between neighboring BSSs. The amount of isolation that is required to allow two BSSs to operate without interfering with each other depends on the attenuation between the BSSs, which would include free space loss, as well as attenuation due to walls, floors, etc. The higher this natural attenuation, the less required from the channel set.

Isolation is achieved in the channel set by defining channels far enough apart in frequency that the transmitted spectrum of a node on one channel is rejected by the receive IF filter of a node on another channel. The IF filter can only reject signals that fall out of band. It is also assumed that the IF filter can be made much sharper than the transmitter shaping filter. Therefore the isolation between any two channels is limited by the amount of energy that each transmits into the others band. Any system designed to take advantage of the availability of isolated channels, must then ensure that its transmitted spectrum is shaped to provide a certain minimum of channel isolation. Without spectrum shaping very few channels can be defined in the available bandwidth.

The number of frequencies to assign in a channel set should be made as large as possible even though channels with adjacent frequencies may give little or no isolation. The addition of these extra channels does not add to the cost of the radio and can be useful to avoid a tone jammer that is present somewhere in the band.

Another requirement of each channel set is that it comply with the 802.11 Par in that the bit rate supported by the PHY be at least 1 Mbit/s. Therefore each channel set must support a bit rate of at least 1 Mbit/s.

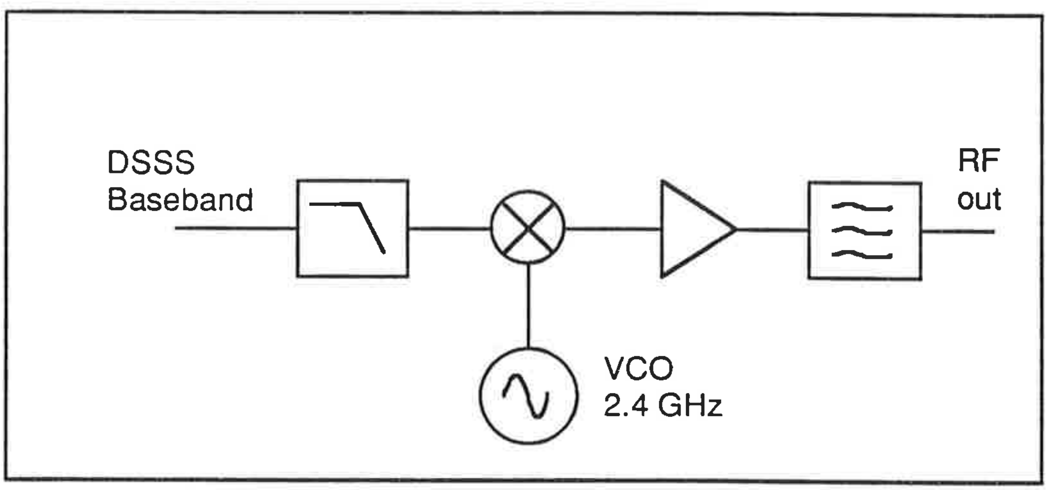


Figure 2.1 DSSS Transmitter Block Diagram

To illustrate that spectrum shaping is possible, a DSSS transmitter was built as in the block diagram of figure 2.1. The output filter covers the 2.4 to 2.5 GHz band, and therefore does not affect the shape of the transmit spectrum.

The actual shaping is done by the low pass filter through which the DSSS baseband signal is passed. Three different channel sets, A, B and C are proposed, that use chip rates of 11, 22 and 5.5 Mchips/s respectively. The transmitters baseband shaping filter was modified for each channel set so that its bandwidth was equal to half the chip rate.

Plots of the transmitter spectrum for each channel set are included. Using these plots, the typical isolation between channels can be determined and the results are shown in tabular form. It is assumed that the two STAs are transmitting at the same power level, therefore isolation is simply taken as the difference between the peak of the transmit spectrum and the power at the 3 dB point of the receive IF filter of the other channel. Since the spectrum is not symmetrical the isolation number was taken from the side with the highest level.

For each chip rate, plots are shown at two different power levels. The centre frequency was arbitrarily picked at 2.46 GHz, however the spectrum shape would be preserved at any frequency in the 2.4 GHz band.

2.1 Channel Set A

It is proposed to base Channel Set A on a chip rate of 11 Mchips/s as proposed by NCR in doc:IEEE P802.11-93/37. The 11 chip Barker code using DQPSK modulation, as in the NCR proposal, would result in a bit rate of 2 Mbits/s and would be the primary channel at each of the nine frequencies of the channel set.

Each frequency would also have 3 fall back channels, the first of which using DPSK to achieve 1 Mbit/s was also proposed by NCR. The benefits of this fallback channel over the primary channel are a minimum of 3 dB better receive sensitivity and better multi-path performance. The other fallback channels use a 22 chip code (2 concatenated 11 chip codes) and a 31 chip code to obtain 3 and 5 dB of extra processing gain.

The proposed frequencies are shown in table 2.1.1 and are spaced 8 MHz apart. The lower and upper frequencies were picked with the FCC requirement of being 20 dB down at the band edge in mind.

Channel #	Centre Frequency
1	2408
2	2416
3	2424
4	2432
5	2440
6	2448
7	2456
8	2464
9	2472

Table 2.1.1 Channel Set A Frequencies

	11 Mchips/s		
Channel	**Bit Rate**	**Modulation**	**Code Length**
Primary	2 Mbits/s	QPSK	11
Fall back 1	1 Mbit/s	DPSK	11
Fall back 2	500 kbits/s	DPSK	22
Fall back 3	355 kbits/s	DPSK	31

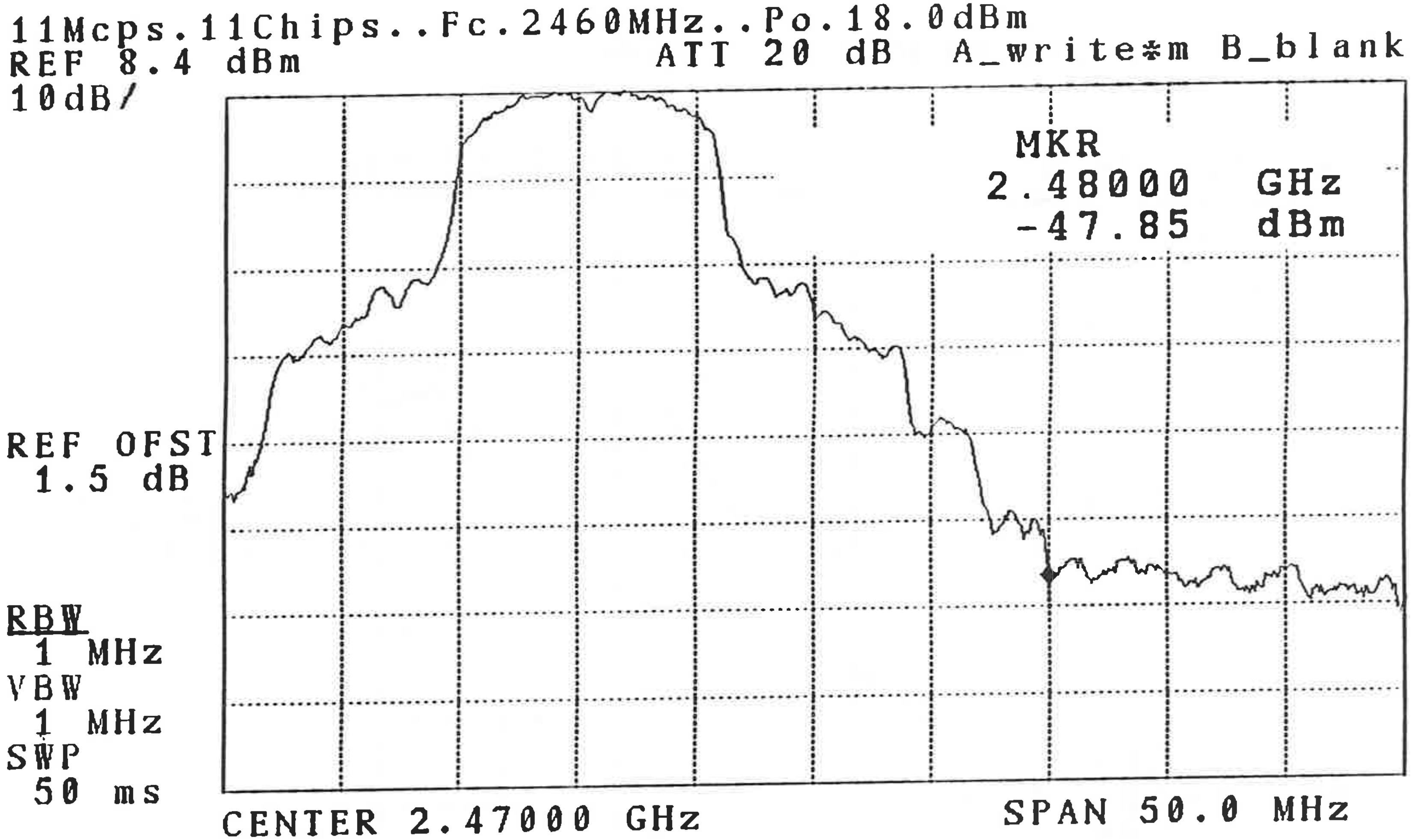
Table 2.1.2 Channel Set A Primary and Fall back Channels

The amount of isolation that was obtained between frequencies is shown in the table 2.1.3. The isolation is strictly a matter of the transmit spectrum side lobe attenuation, which is dependent on the linearity of the mixer and power amplifier. The power amplifier used is rated at an output power of 28 dBm. Adding 3 dB for the output filter and 2 dB for a diode switch the actual power output that could be achieved is about 23 dBm. As can be seen from table 2.1.3 the amplifier was running at well below this level to maintain linearity. As the output power was increased and the amplifier went into compression, the skirts of the spectrum shape increased reducing the isolation.

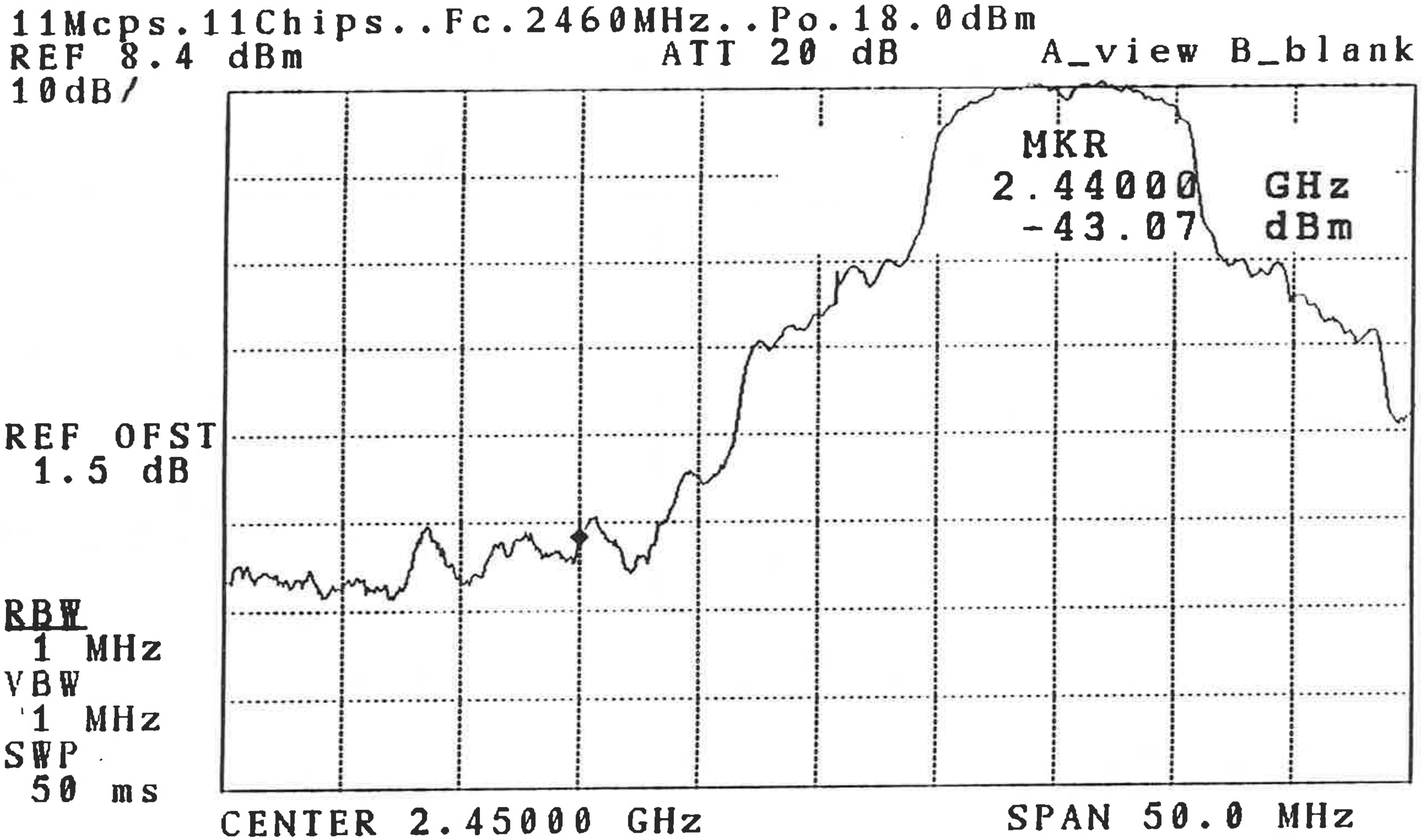
	Channel Isolation			
Output Power	8MHz	16 MHz	24 MHz	32 MHz
18 dBm	2 dB	26 dB	50 dB	50 dB
15 dBm	2 dB	36 dB	55 dB	55 dB

Table 2.1.3 Channel Isolation for Channel Set A

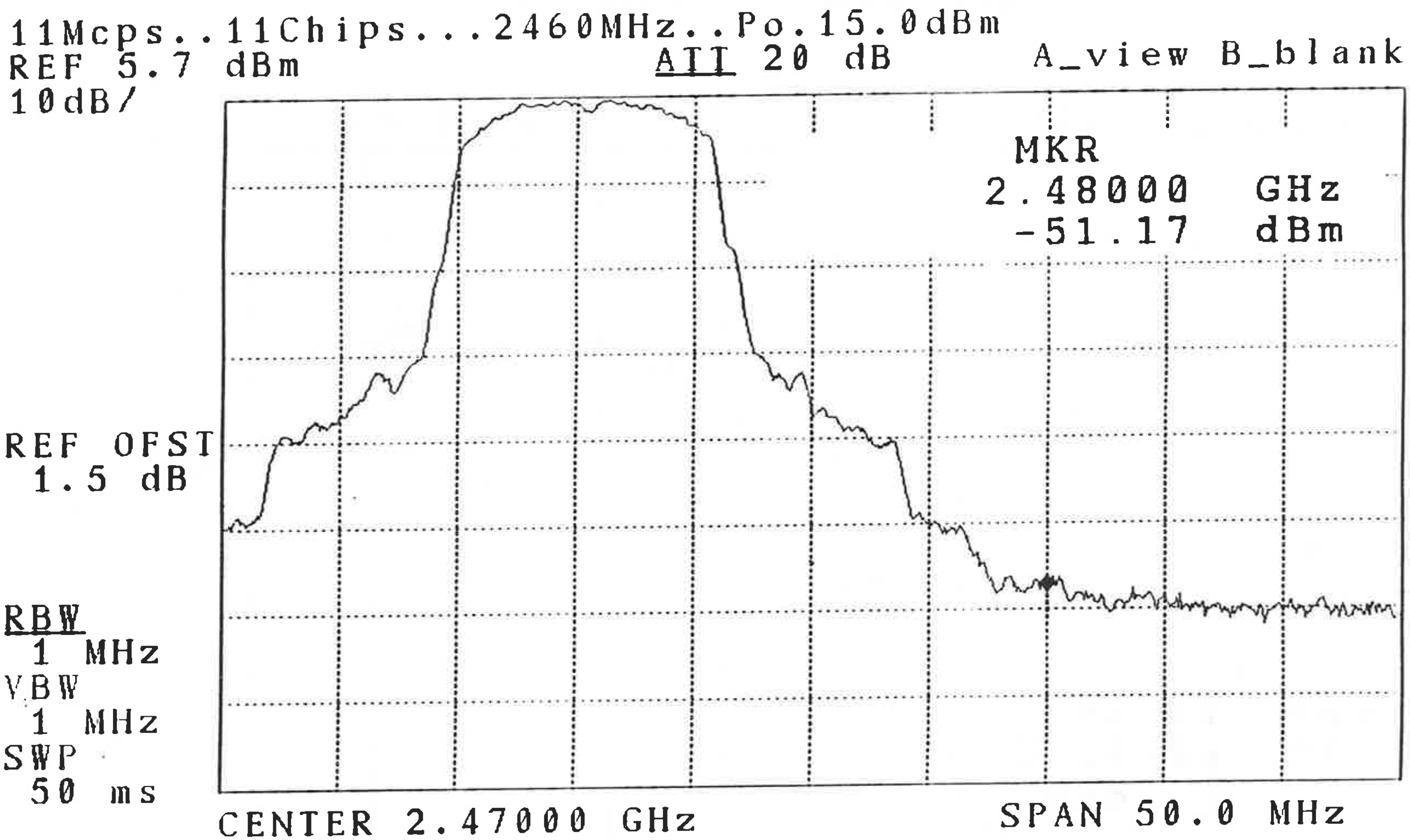
The baseband filter used was a 5 pole discrete low pass filter with a corner frequency of 5 MHz. As can be seen from the table above a 3 dB reduction in output power resulted in a 10 dB improvement in isolation between two channels 16 MHz apart. The IF filter assumed in deriving the above numbers is an 11 MHz band pass filter.



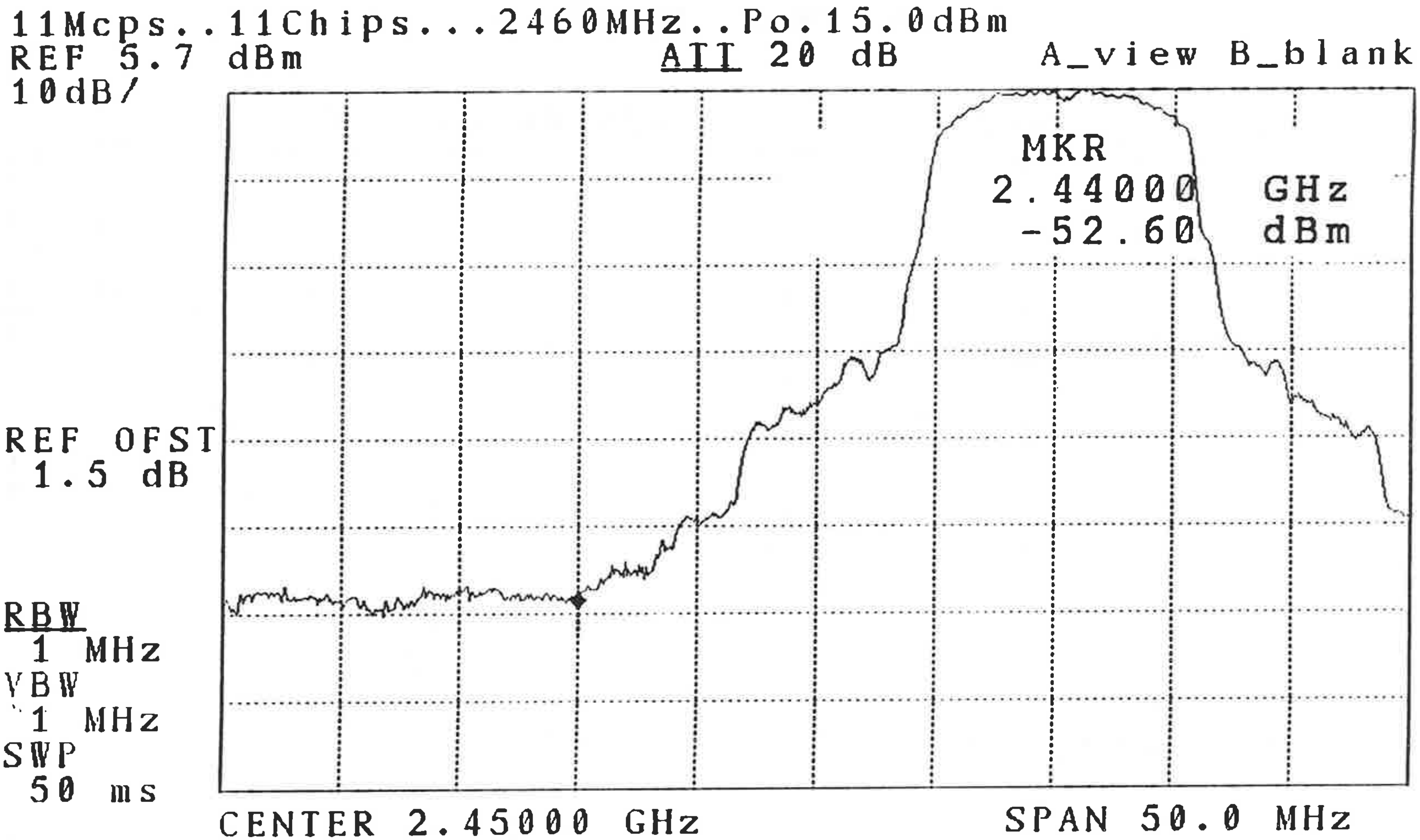
Channel Set A - Transmit Spectrum



Channel Set A - Transmit Spectrum



Channel Set A - Transmit Spectrum



Channel Set A - Transmit Spectrum

2.2 Channel Set B

With DSSS it is possible to easily obtain higher bit rates by increasing the chip rate used. An optional second channel set is proposed that uses twice the chip rate (22 Mchips/s). The shaping filter and IF filter corner frequencies would also have to double. The same channel spacing is proposed with the exception that the lowest and highest channels are removed in order to comply with the FCC 20 dB band edge requirement. Although not much isolation advantage is gained by these widely overlapping channels, they are still useful if trying to avoid a tone jammer.

Channel #	Centre Frequency
1	2416
2	2424
3	2432
4	2440
5	2448
6	2456
7	2464

Table 2.2.1 Channel Set B Frequencies

As in Channel Set A, each frequency would then have a primary channel plus the same three fall back channels as shown in table 2.2.2.

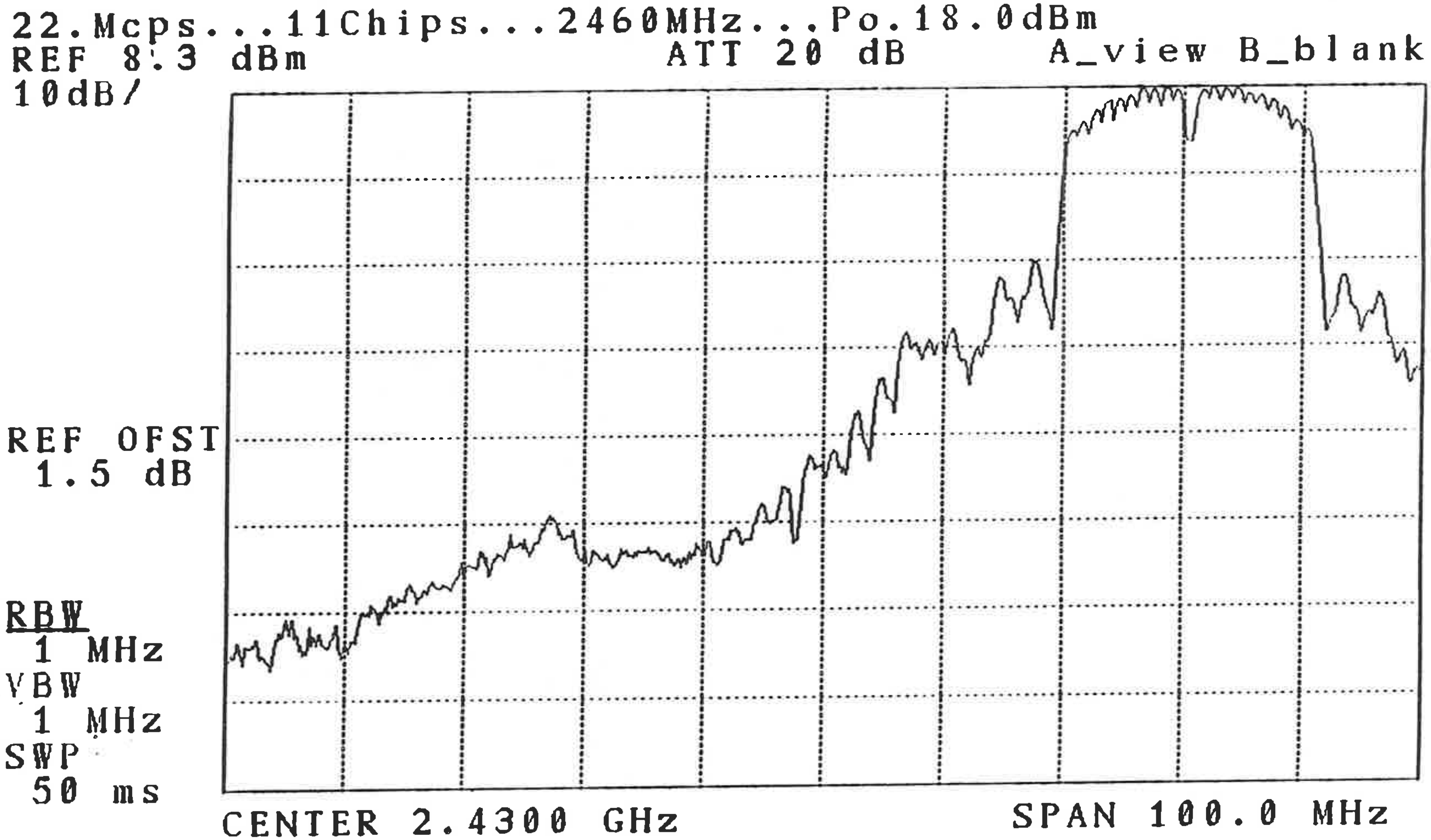
The baseband filter used was a 5 pole discrete low pass filter with a corner frequency of 10 MHz. The channel isolation that can be obtained with this channel set is outlined in the table 2.2.3 below. With this very wide spreading it is obvious that a lot more bandwidth is needed (as provided in the 5.7 GHz band), to achieve good isolation for more than two simultaneous channels.

	22 Mchips/s		
Channel	**Bit Rate**	**Modulation**	**Code Length**
Primary	4 Mbits/s	QPSK	11
Fall back 1	2 Mbit/s	DPSK	11
Fall back 2	1 Mbits/s	DPSK	22
Fall back 3	710 kbits/s	DPSK	31

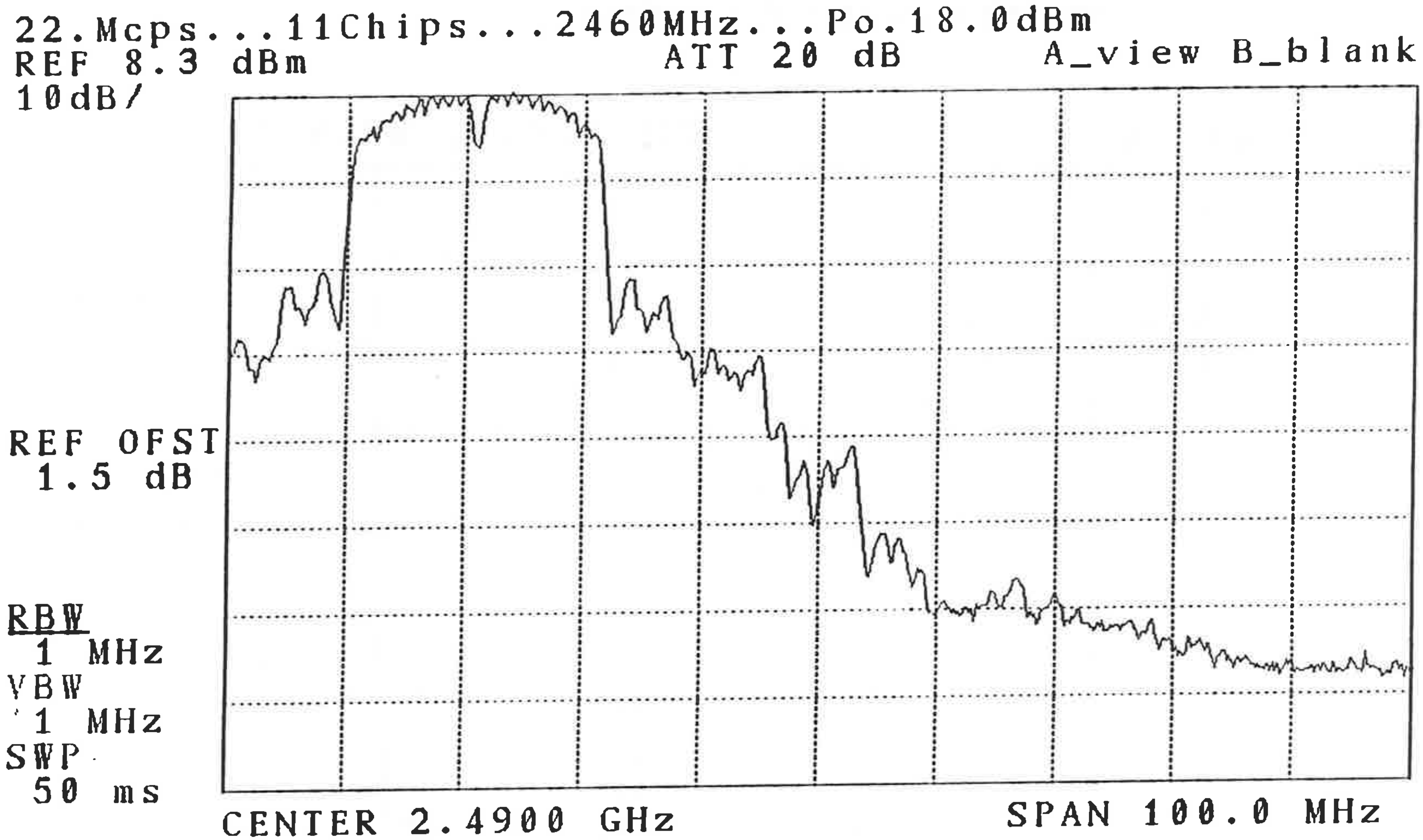
Table 2.2.2 Channel Set B Primary and Fall back Channels

	Channel Isolation			
Output Power	8MHz	16 MHz	24 MHz	32 MHz
18 dBm	0 dB	2 dB	20 dB	30 dB
15 dBm	0 dB	2 dB	30 dB	38 dB

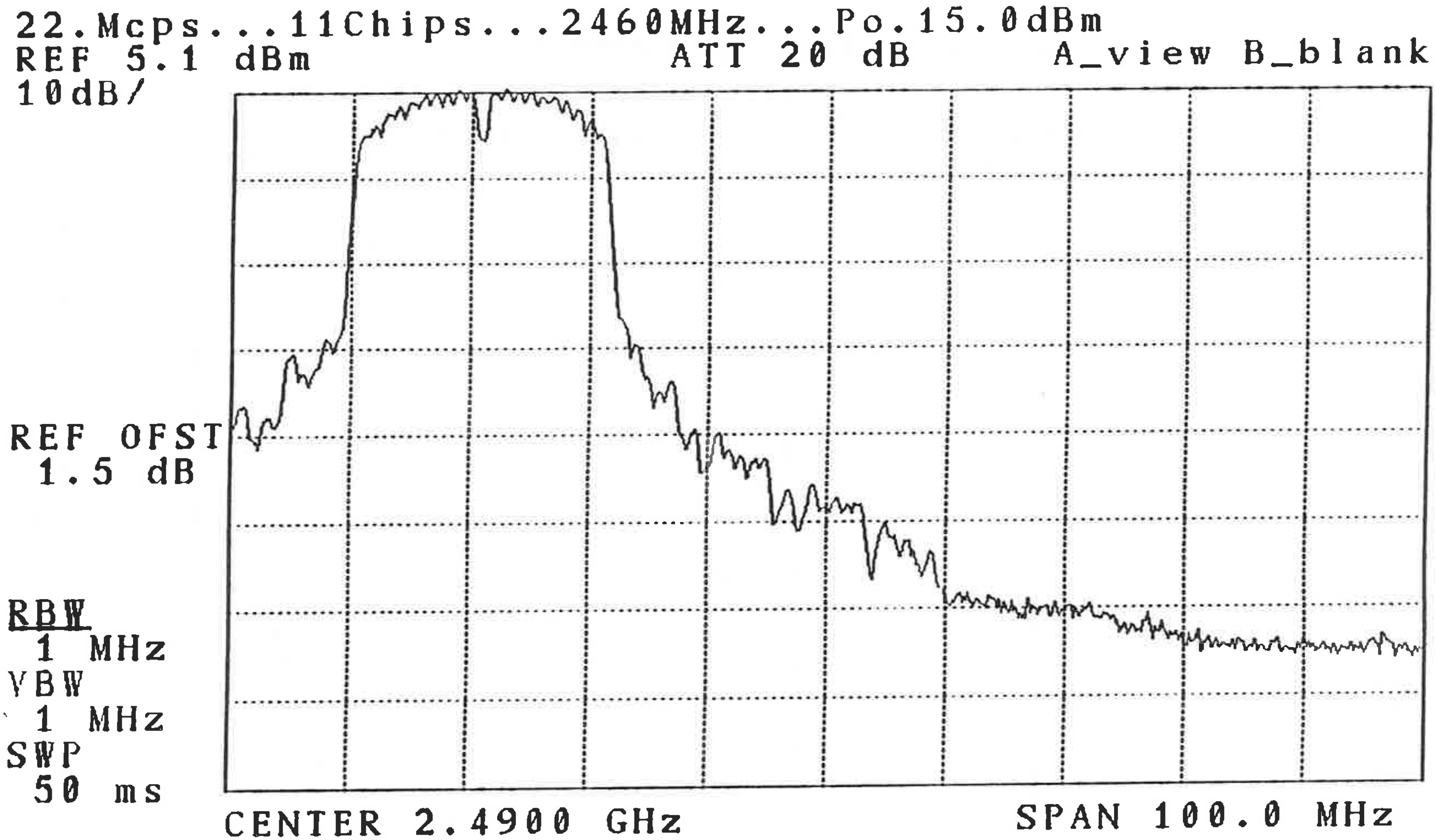
Table 2.2.3 Channel Isolation for Channel Set B



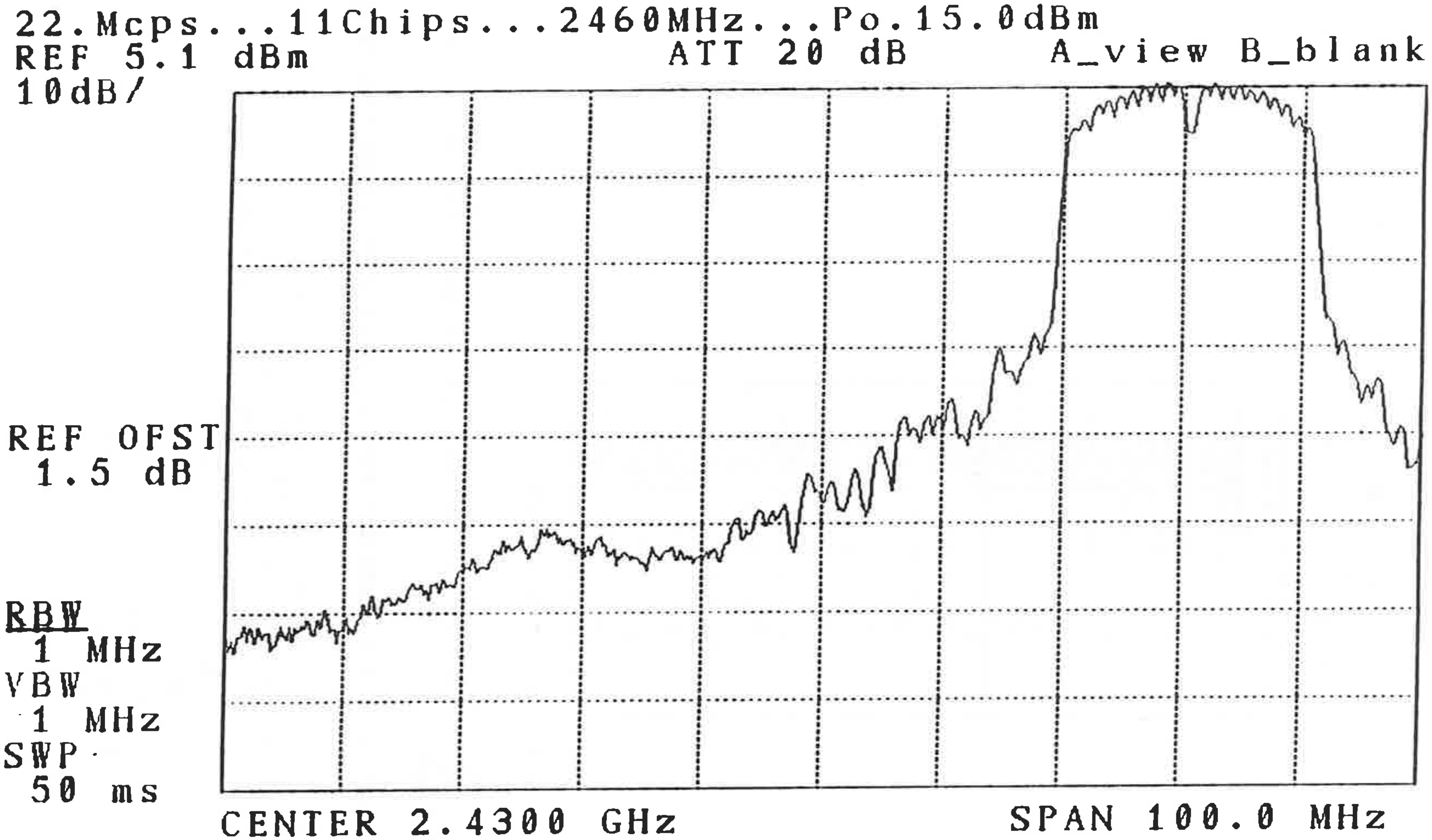
Channel Set B - Transmit Spectrum



Channel Set B - Transmit Spectrum



Channel Set B - Transmit Spectrum



Channel Set B - Transmit Spectrum

2.3 Channel Set C

Taking Channel Set A as a starting point and halving the chip rate, it is possible to create twice as many channels with the same effective isolation. It is proposed that Channel Set C have channels spaced 4 MHz apart as outlined in the table below.

Channel #	Centre Frequency
1	2405
2	2409
3	2413
4	2417
5	2421
6	2425
7	2429
8	2433
9	2437
10	2441
11	2445
12	2449
13	2453
14	2457
15	2461
16	2465
17	2469
18	2473
19	2477

Figure 2.3.1 Channel Set C Frequencies

Again, to take advantage of the narrower channel, both the TX shaping filter and the IF filter must be halved in bandwidth. The baseband filter used was a 5 pole discrete low pass filter with a corner frequency of 2.5 MHz.

As in Channel Set A, each frequency would then have a primary channel plus 3 fall back channels.

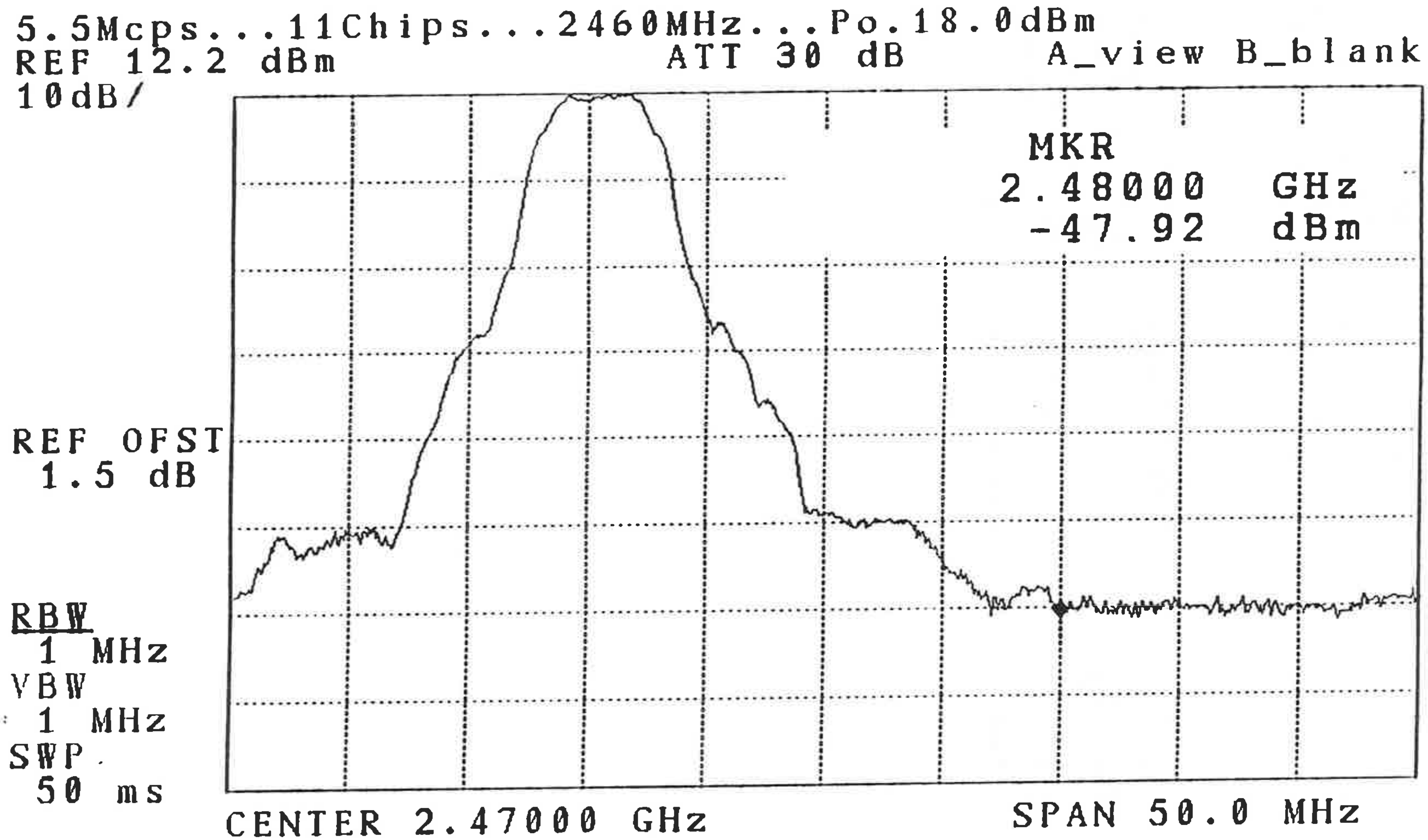
	5.5 Mchips/s		
Channel	**Bit Rate**	**Modulation**	**Code Length**
Primary	1 Mbit/s	QPSK	11
Fall back 1	500 kbits/s	DPSK	11
Fall back 2	250 kbits/s	DPSK	22
Fall back 3	177 kbits/s	DPSK	31

Table 2.3.2 Channel Set C Primary and Fall back Channels

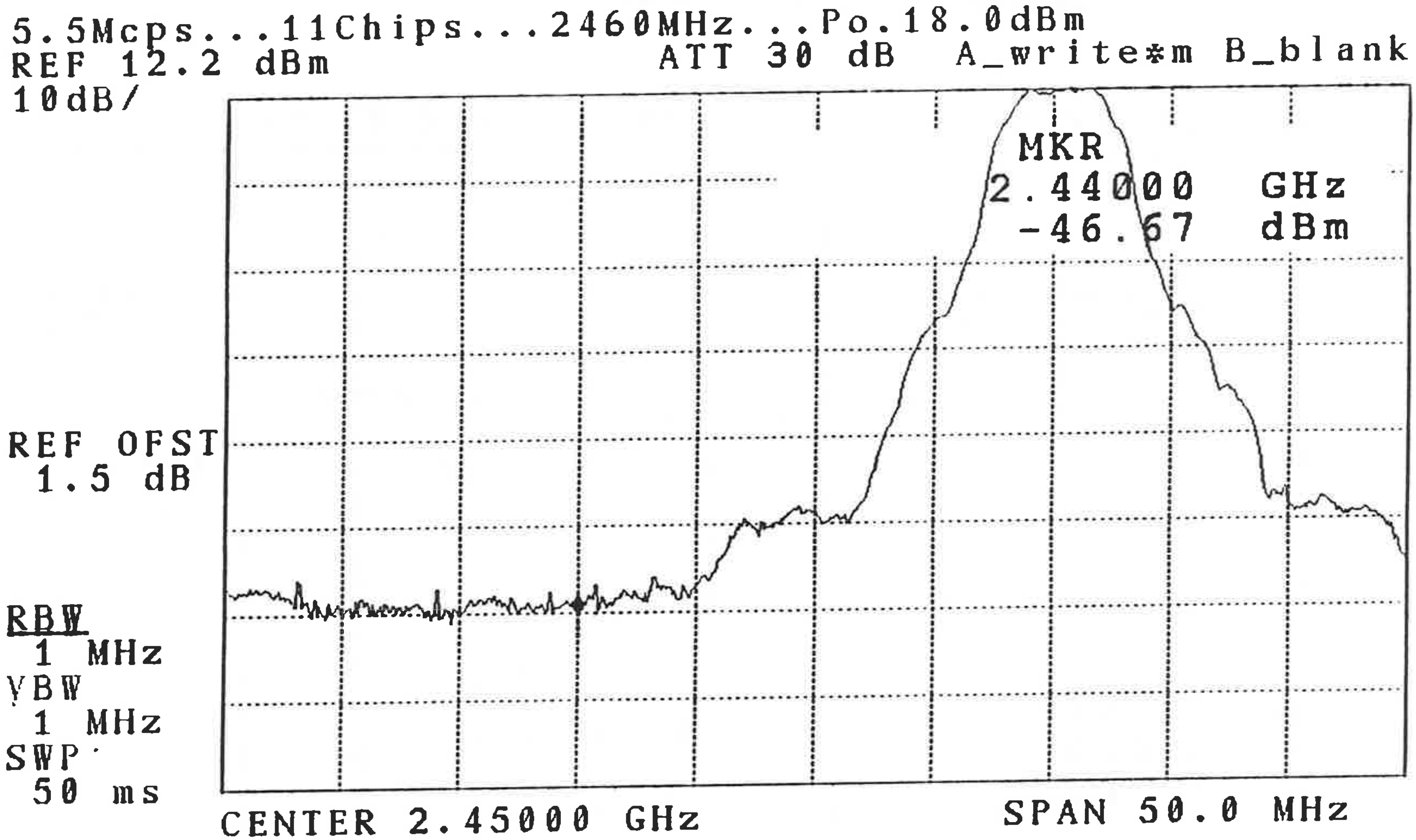
The Channel isolation that can be obtained with this channel set is outlined in the table 2.3.2. As can be seen from the spectrum plots, the side lobes at either side of the main lobe degrades the isolation between two channels 16 MHz apart by almost 10 dB. These side lobes were found to be caused by spurs in the LO rather than modulation harmonics of the spread spectrum signal. In a proper design these spurs would be removed and thus better isolation achieved three channels away.

	Channel Isolation				
Output Power	4MHz	8 MHz	12 MHz	16 MHz	20 MHz
18 dBm	2 dB	25 dB	48 dB	48 dB	58 dB
15 dBm	2 dB	36 dB	50 dB	53 dB	62 dB

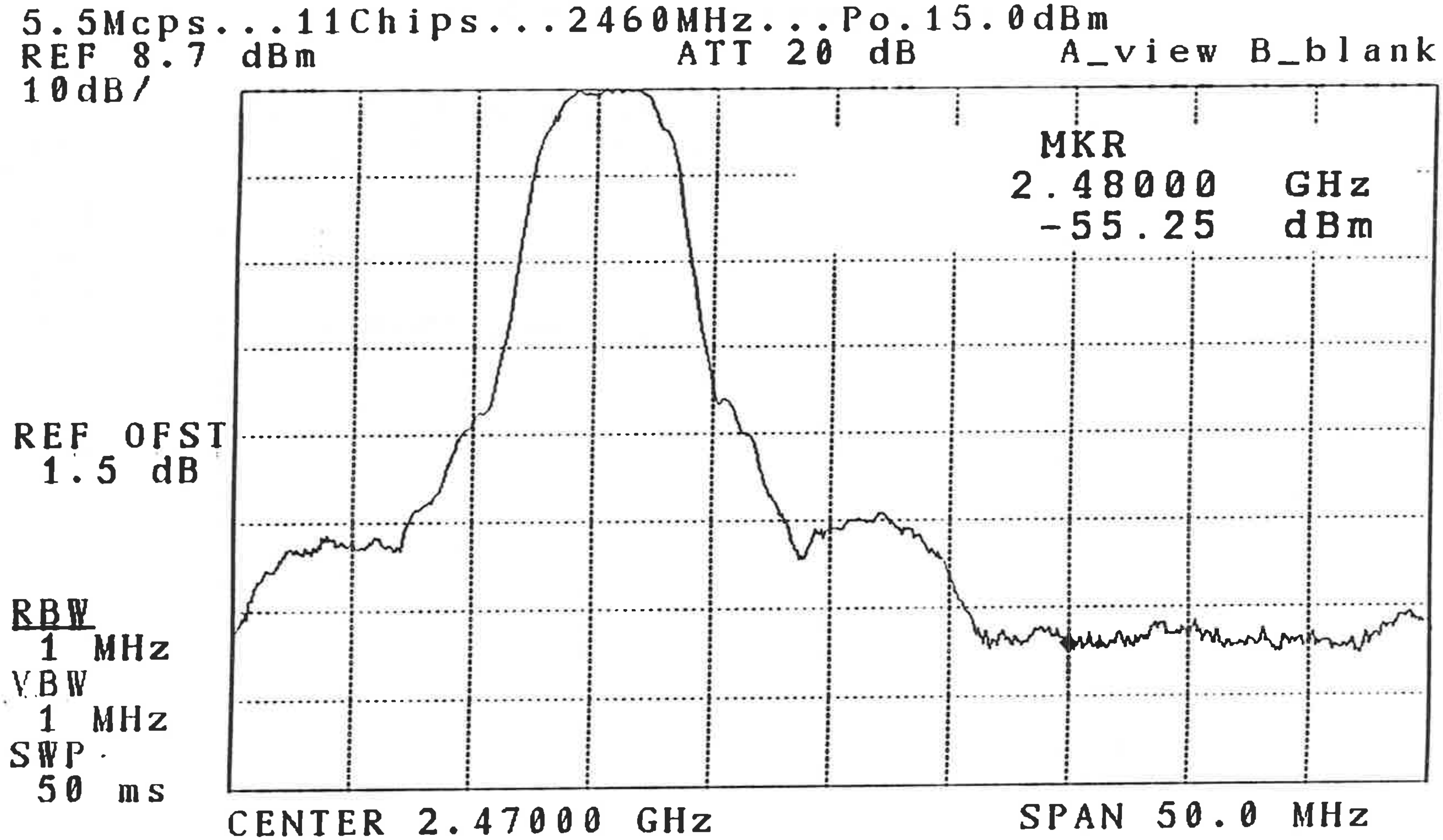
Table 2.3.3 Channel Isolation for Channel Set C



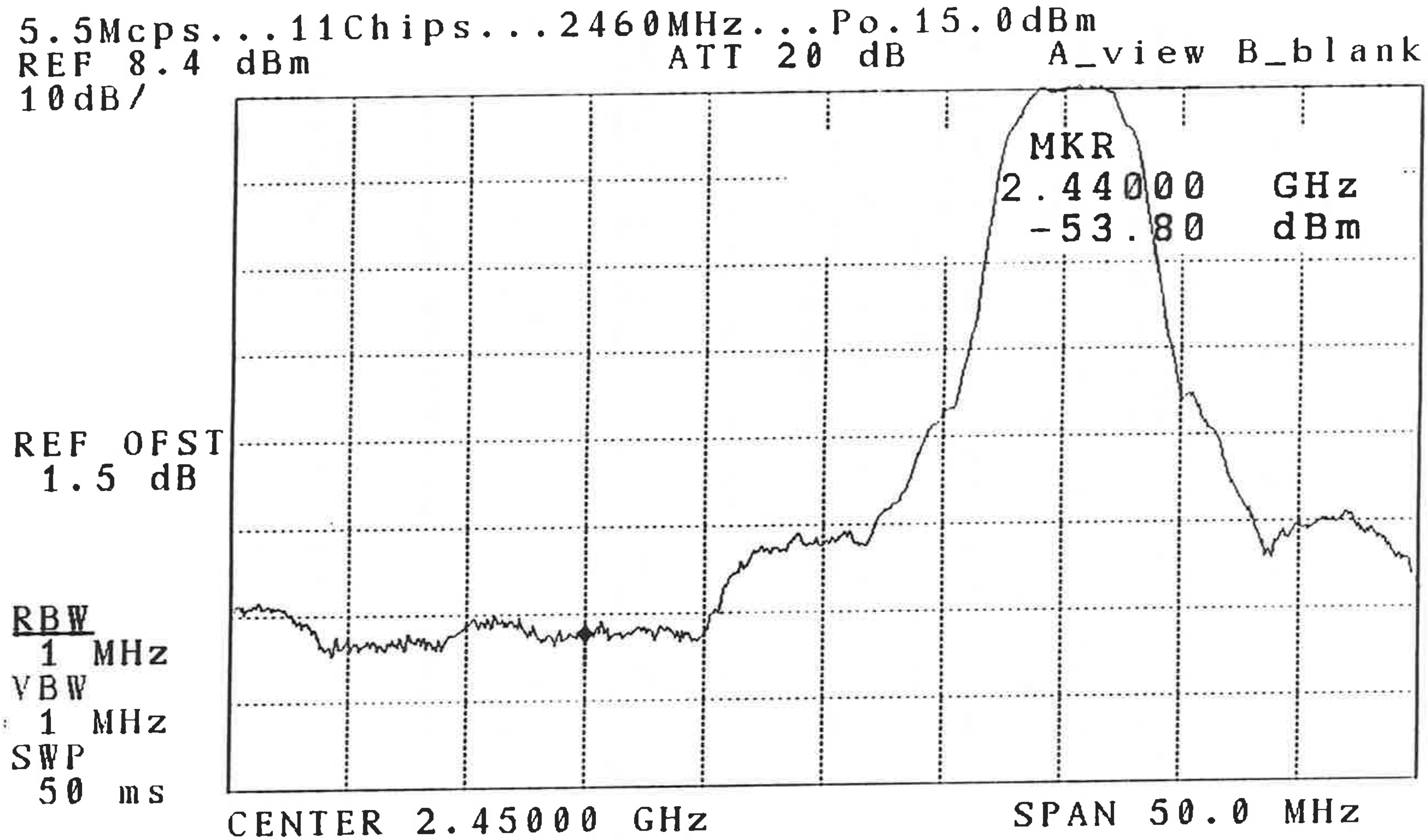
Channel Set C - Transmit Spectrum



Channel Set C - Transmit Spectrum



Channel Set C - Transmit Spectrum



Channel Set C - Transmit Spectrum

3.0 Discussion

With 83 MHz of bandwidth available,three channel sets are proposed for high, mid and low data rates in which the whole band is covered. To achieve an acceptable level of channel isolation it is clear that the 802.11 specification for a DSSS PHY **must specify** an output spectrum template that must be met to assure compliance. The template should be specified in absolute levels and should be determined after discussions on what can and cannot be done with current and near future technology.

The ability to support multiple channel sets in one PHY is not beyond today's capabilities, and it can be left up to the vendor whether he wants to develop a product that can work at both high and low data rates. (Similar to Token Ring cards that work at both 4 and 16 Mbits/s).

Since filters must change when going from one channel set to another, the lowest cost solutions would probably support only one channel set. On the other hand, a radio can be designed to switch filters depending on the channel set used.

The primary purpose of using Channel Set B is to get the higher data rate. The ability to co-locate multiple (>2) BSSs is sacrificed, with each BSS having an independent channel. In applications where throughput is most important, this tradeoff may not be a problem.

Channel Set C gives the most channels with good simultaneous isolation. This channel set easily lends itself to creating an ESS where one can reuse bandwidth. The drawback is that each user has access to a lower data rate. There are definitely markets where total coverage of a facility is required and 1 Mbit/s is sufficient.

Channel Set A is the best compromise between channel sets B and C. It supports higher data rates than C and has more independent channels than B.

When a user is faced with too high a load in a single BSS, he has the option of splitting the load by creating two BSSs and keep the same channel set, or stay with one BSS and use a channel set that has twice the bit rate.

The results outlined in this paper were obtained with a relatively simple design. The channel sets proposed represent something that is readily achievable with today's technology and can result in a high performance, low cost, radio design.

The following items could bear further discussion within the 802.11 PHY subgroup forum.

- Is 30 - 50 dB of channel isolation sufficient in real world installations?
- Does the importance of independent channels exceed the need for maximum power?
- What are the implications of requiring an output spectrum template?
- What is the impact of different output power levels on channel isolation?