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TITLE

D6470 EHF SATCOM PAYLOAD DOWN CONVERTER UNIT

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D6470 EHF SATCOM PAYLOAD DOWN CONVERTER UNIT

by

Claude Bélisle and David Barlow

CRC TECHNICAL NOTE 96-001

December 1995
Ottawa

Industry and Science Canada
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The work described in this document was sponsored by the Department of National Defence under Task 041LL-A2.

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COMMUNICATION RESEARCH CENTRE INDUSTRY AND SCIENCE
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RÉSUMÉ

Dans le cadre du project D6470 du département de la défense nationale, portant sur les communications par satellite dans la bande sub-millimétrique (EHF), un certain nombre de composantes ont été développées dans les laboratoires du gouvernement pour supporter le développement de la technologie. Ce rapport décrit l'unité de conversion de fréquences de la charge utile du satellite, conçue, assemblée et vérifiée au CRC. Cette unité est responsable de transposer le signal à saut de fréquences reçu dans la bande 43.5 à 45.5 GHz à un signal à fréquence centrale fixe de 20 MHz. L'unité offre un gain de 80 dB, une figure de bruit de 11.7 dB et un point de compression 1 dB à 19dBm. La puissance de sortie, à 20 MHz est maintenue à ±1.5 dB pour tout signal d'entrée compris dans la bande spectrale entre 43.5 et 45.5 GHz.

ABSTRACT

As part of the Department of National Defence D6470 project, related to satellite communications in the extremely high frequency (EHF) band, a number of components were developed in-house to support the development of the technology. This report describes the frequency down conversion unit designed, assembled and tested at CRC. The down converter unit is responsible for receiving a 43.5 to 45.5 GHz frequency hopped signal and to convert it to a 20 MHz dehopped signal. The unit has a gain of 80 dB, a noise figure of 11.7dB and a 1 dB compression point of 19 dBm. The output power level is maintained within ±1.5 dB for any signal falling in the input frequency band.

EXECUTIVE SUMMARY

In this report, the design and testing of a frequency downconversion unit are described. This unit was built as part of the CRC in-house support to the Department of National Defence D6470 project, related to satellite communications in the extremely high frequency (EHF) band. The frequency down conversion unit described translates the 43.5 to 45.5 GHz received frequency hopped signal to a 20 MHz dehopped signal for further processing. The unit is built around commercially available components. Its main specifications are, a gain of 80 dB, a noise figure of 11.7dB and a 1 dB compression point of 19 dBm. The output power level is maintained within ±1.5 dB for any signal falling in the input frequency band.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Department of National Defence has initiated a major research and development project in satellite communications in the extremely high frequency (EHF) band. To this end, the Defence Research Establishment Ottawa (DREO) was given the responsibility to manage and supervise R&D activities for the development of an advanced development model of an EHF frequency hopping satellite communications system. An industrial contract has been issued for the fabrication of a ground terminal and a payload simulator. In support of this contract, in-house R&D activities are being conducted on critical technologies and concepts. The ground terminal portion of the system is being investigated by the DREO team while the payload portion was issued to the military satellite communications (MilSatCom) group at the Communications Research Centre (CRC).

One of the key feature of this system is that the payload is to process the information for error correction, traffic monitoring, rather than being just a conventional "bent-pipe". Consequently, frequency conversions are required, in the payload, to down convert the incoming EHF frequency to baseband for processing and to up convert the signal back to EHF for retransmissions. Fig. 1 shows a simplified block diagram of the payload functions.

1.2 SCOPE

The scope of this report is to describe the frequency down conversion unit designed, assembled and tested as part of the D6470 in-house payload simulator. The down converter unit is responsible for receiving a 43.5 to 45.5 GHz frequency hopped signal and to convert it to 20 MHz (dehopped).

1.3 REPORT ORGANIZATION

This report is divided into 7 chapters. In chapter 2, a description of the frequency down converter unit is given. Chapter 3 describes the test bed while chapters 4 to 7 give the results of the performance evaluation in terms of noise figure, 1-dB compression point, two-tone intermodulation and linearity.

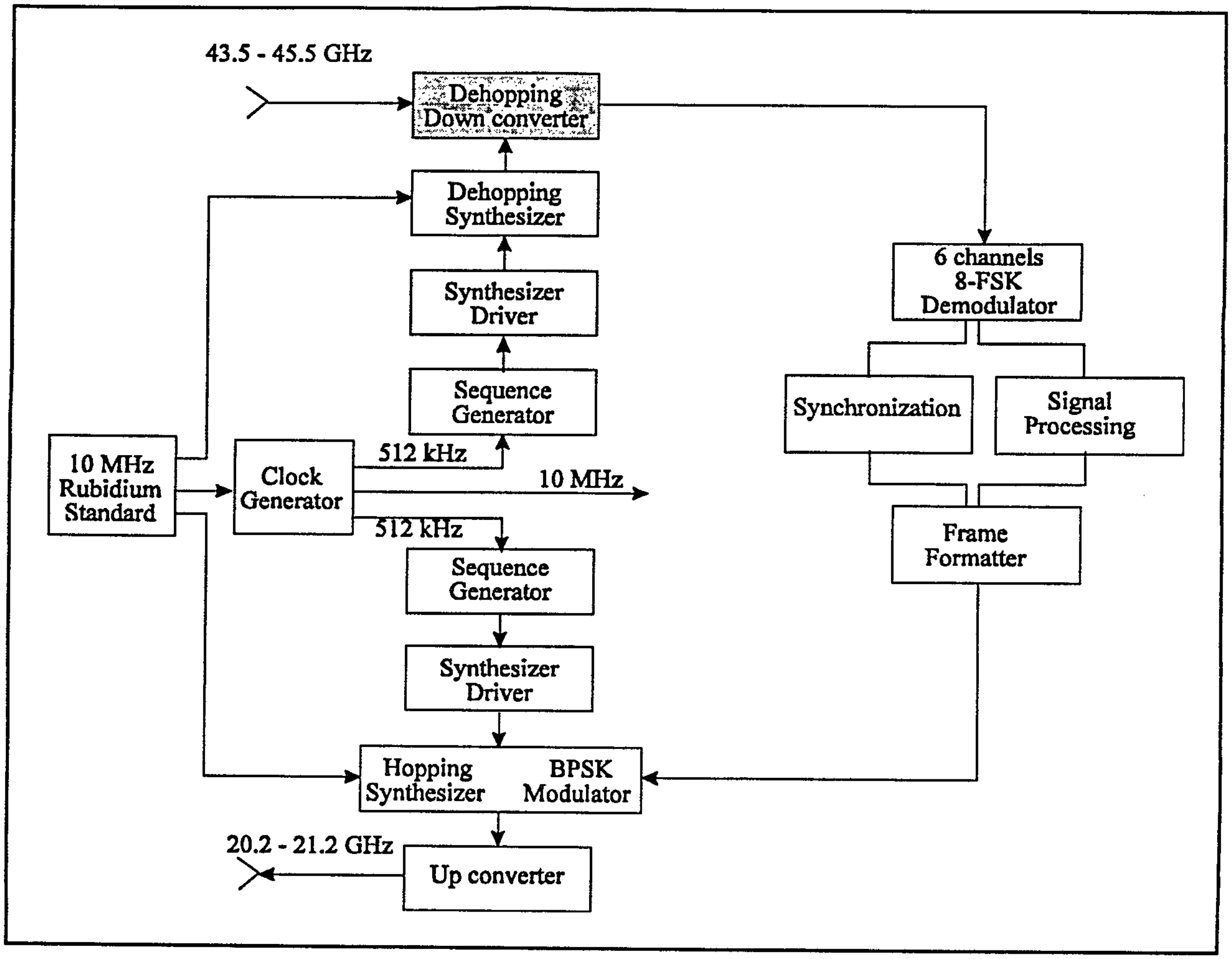

Figure 1 Simplified block diagram of the payload functions

2.0 FREQUENCY DOWN-CONVERTER UNIT DESCRIPTION

The frequency down conversion unit was built to bring a 43.5 to 45.5 GHz frequency hopped signal to a 20 MHz dehopped signal, for input into a block demodulator. Fig. 2 shows the block diagram of the down converter unit while Figs. 3 and 4 are pictures of the actual unit.

The received signal is first filtered to accept only those signals within a 3 dB bandwidth of 2.5 GHz around 44.5 GHz (43.25 to 45.75 GHz). The first down-conversion stage brings the frequency hopping input signal to a dehopped IF signal of 9.4275 GHz. The local oscillator (LO) signal, at 35.0725 GHz, is produced from mixing the signal of a 6 to 8 GHz hopping synthesizer with the third harmonic of a 9.375 GHz phase locked oscillator. The IF signal, at 9.4275 GHz is filtered and amplified by a 35 dB low noise amplifier. A second stage of down conversion brings this 9.4275 GHz signal to a 70 MHz using the signal from the phase locked oscillator. Finally, the signal is brought down to 20 MHz using the fifth harmonic (produced by a comb generator) of a 10 MHz reference signal. This 10 MHz signal is provided by a rubidium standard, external to the down conversion unit.

It must be noted that contrary to most receivers, the input signal is first dehopped and the resulting IF signal filtered before any amplification is done. It is understood that this will raise the overall system noise figure but this was done to prevent saturation of the preamplifier by interfering signals (jammer).

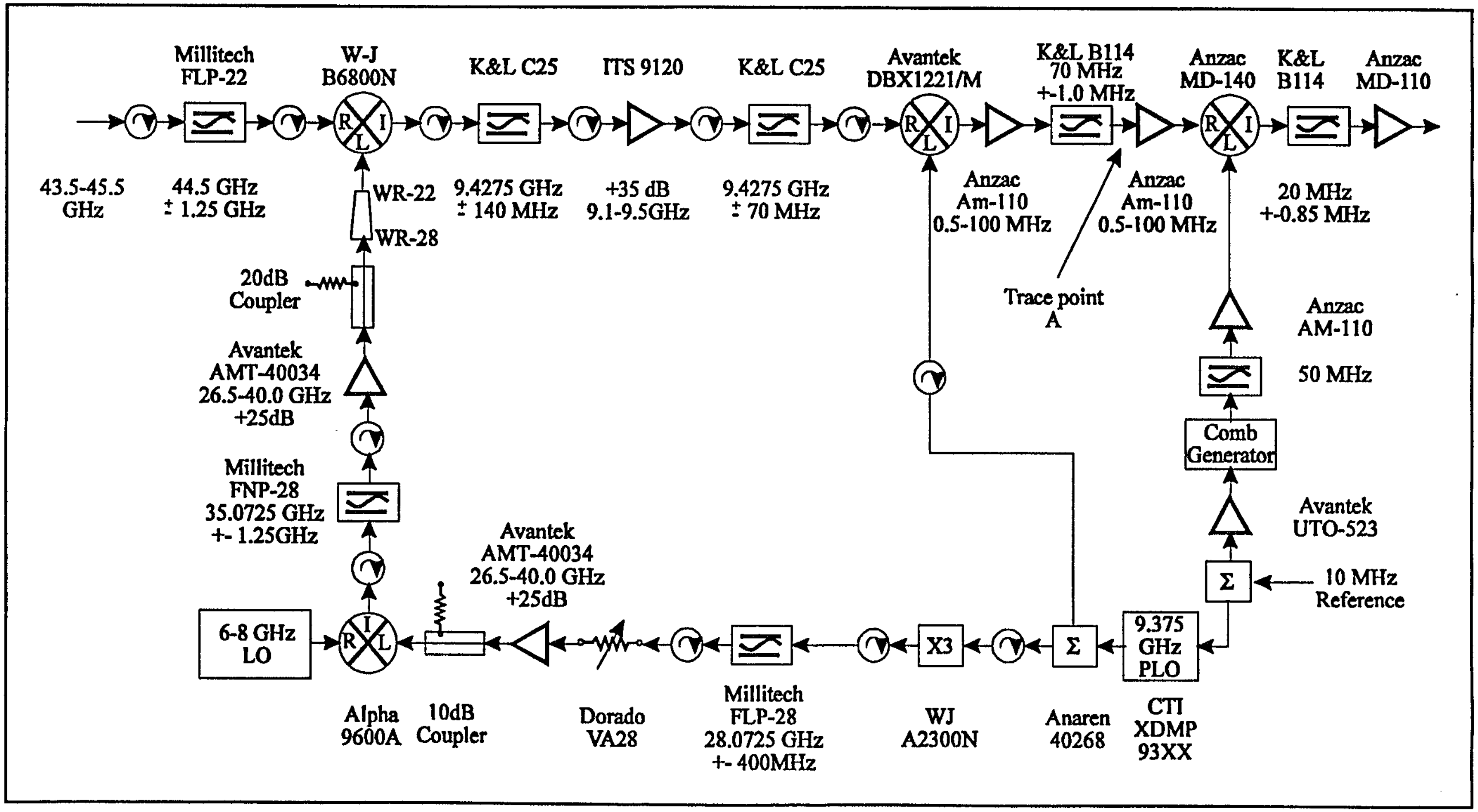

Figure 2 Frequency down-converter block diagram

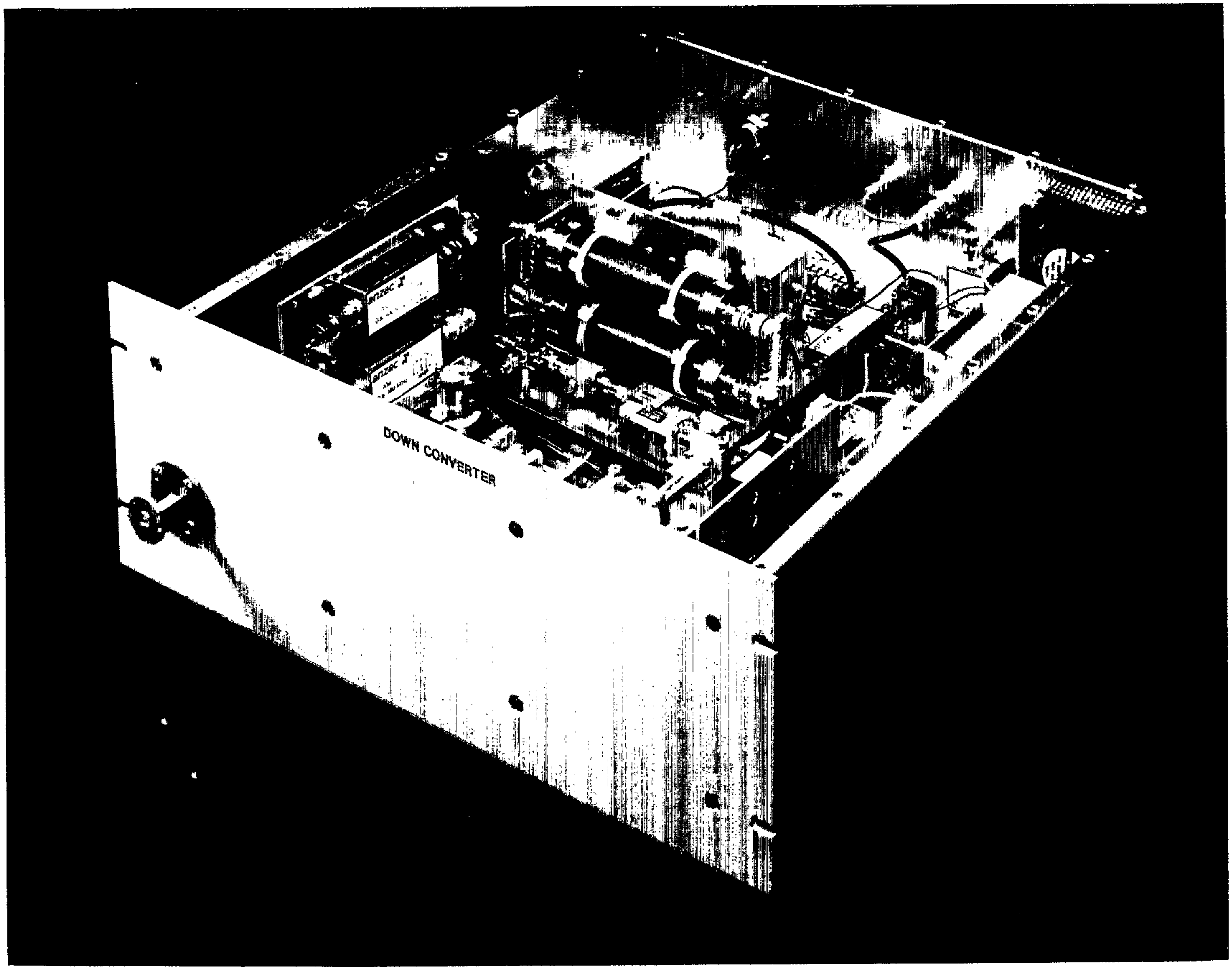

Figure 3 Picture of the down-converter unit.

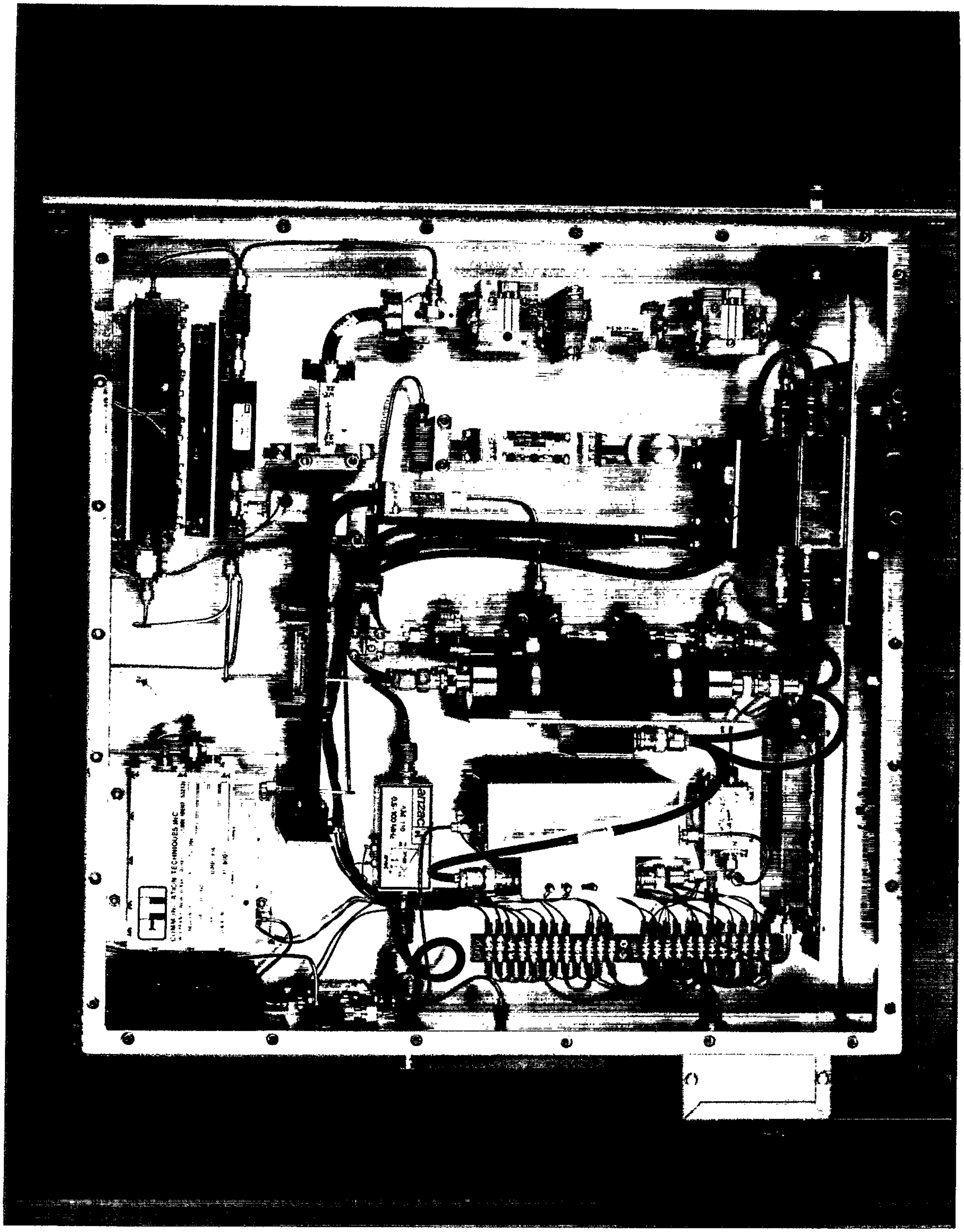

Figure 4 Top view of the down-converter unit.

3.0 TEST BED

In order to test the down converter unit, two signal sources were assembled: a 43.5 to 45.5 GHz source to provide the input signal and a 6 to 8 GHz one to act as the dehopping frequency synthesizer in the receiver. Fig. 5 shows the block diagram of the 43.5 - 45.5 GHz source while Fig. 6 shows the dehopping synthesizer.

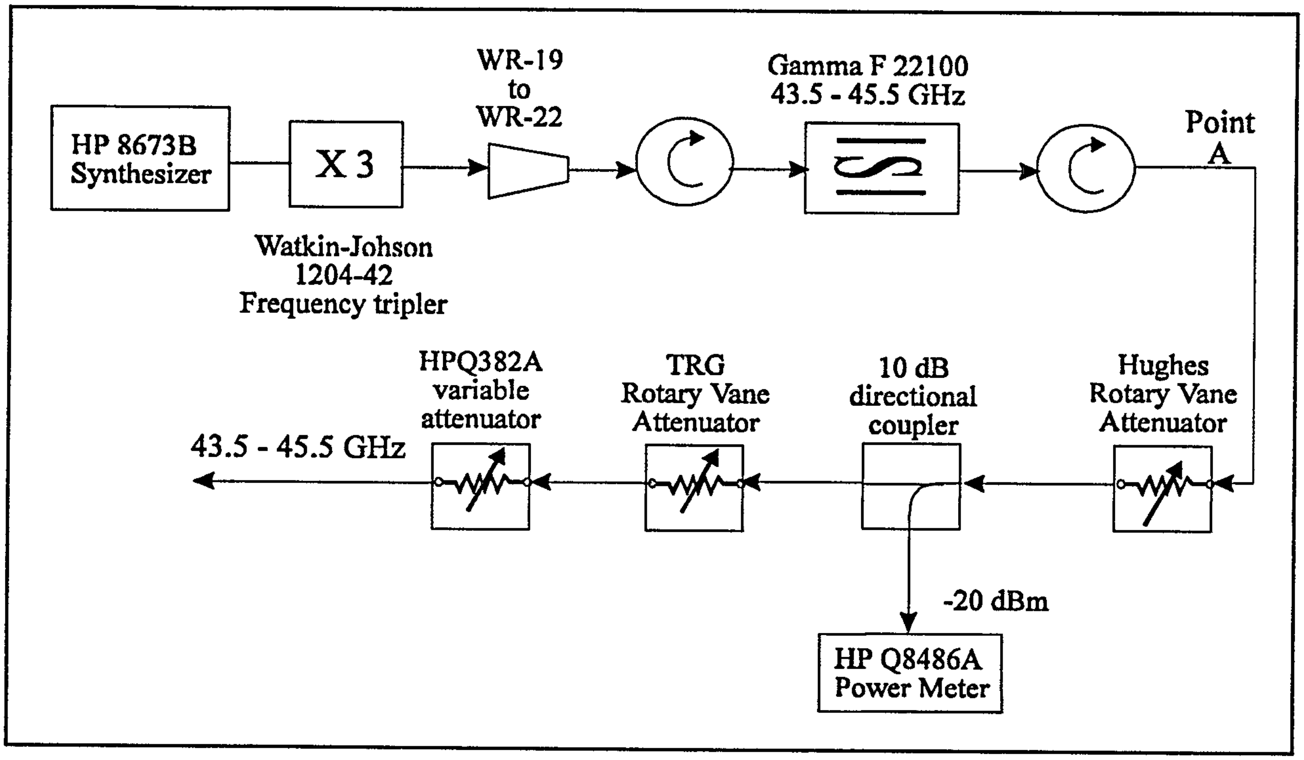

Figure 5 44.5 GHz source used as the input signal to the down-converter unit.

For the input source, an HP 8673B signal generator was used to output an RF signal in the range of 14.8 GHz. This signal was fed through a Watkins Johnson frequency extender, model 1204-42, which tripled the input frequency to a range between 43.5 to 45.5 GHz. The W-J tripler used WR-19 waveguide, so a WR-19 to WR-22 transition was connected. To provide some protection to the tripler and reduce mismatch problems as much as possible, a Hughes full band ferrite isolator, model #47722H, was connected to the transition. Because the tripler is a non-linear device, a waveguide bandpass filter was installed to reduce out-of-band harmonics and spurious signals. The filter was made by Gamma-F, model #22100. Another Hughes isolator was added to the setup, following the filter.

The W-J frequency tripler was driven with a 0 dBm signal from the HP 8673B signal generator. The tripler output level, measured at point A on Fig. 5 was +1.24 dBm. A built-in amplifier in the W-J tripler gave the power gain. The measurement was done with an HP

Q8486A power head and an HP 436A power meter inserted at point A on Fig.5.

To provide the range of output levels required, attenuators were added at the end of the circuit, as shown in Fig. 5. The attenuators were all calibrated individually and in series (up to three). However, because of the power handling range of the Q8486A power meter, power levels could only be measured down to -30 dBm. For that reason, a 10 dB directional coupler was included in the network and the Hughes rotary vane was adjusted to maintain a -20 dBm power level for all frequencies. The other two calibrated attenuators were set to obtain the desired signal levels.

The 6 to 8 GHz local oscillator of the down converter was based on a direct digital synthesizer (DDS) which provided an RF signal between 1 GHz and 1.999... GHz with a 1 mHz resolution. This signal is mixed with a 2 GHz signal produced from a 2 GHz phase lock oscillator, locked on the 100 MHz clock source from the DDS. The 3-4 GHz RF signal is amplified and doubled to obtain a 6-8 GHz output at +22 dBm with a spurious level at -39dBm.

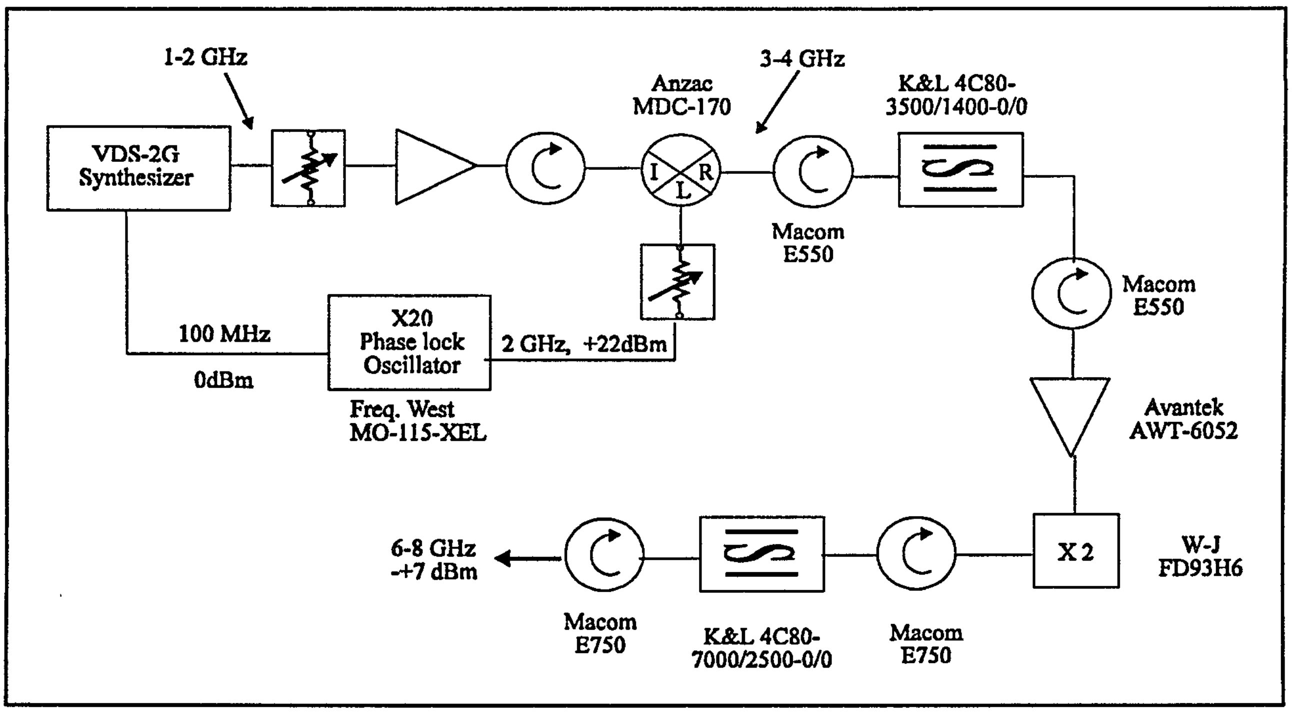

Figure 6 6-8 GHz local oscillator for the down-converter

4.0 NOISE FIGURE MEASUREMENTS

Fig. 7 shows the primary components of the system (Fig. 2) which contribute to the noise figure. Those components are in fact all those up to and including the first amplification stage. Table 1 gives the value of the insertion loss or noise figure of each component in the chain. Those numbers were taken either from the manufacturers catalog or when provided, from the factory specification sheet provided with the component.

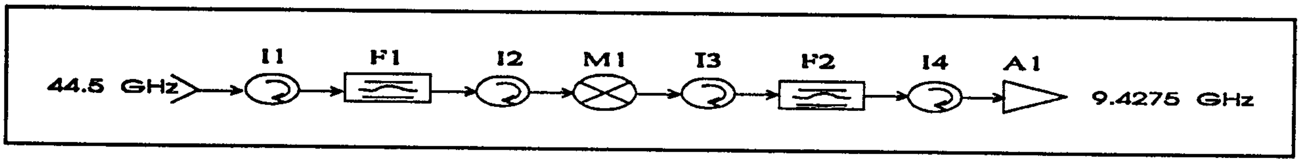

Figure 7 Primary components of the down converter unit (Fig.1) responsible for the system noise figure.

Table 1 Theoretical evaluation of the system noise figure (ID refers to Fig.5).

ID	COMPONENTS	Loss or N.F.
I1	Alpha TRG isolator - insertion loss (data sheet)	0.5 dB
F1	Millitech filter FLP-22 - insertion loss (data sheet)	0.7 dB
I2	Alpha TRG isolator - insertion loss (data sheet)	0.5 dB
M1	Watkins-Johnson mixer 36800N - conversion loss (catalog)	5.0 dB
I3	Innowave Isolator 1095IS - insertion loss (data sheet)	0.3 dB
F2	K&L 4C52-9427 filter - insertion loss (catalog)	1.31 dB
I4	Innowave Isolator 1095IS - insertion loss (data sheet)	0.3 dB
A1	ITS-9120 low noise amplifier, - noise figure (measured by CRC)[1]	1.9 dB
	Total Theoretical Noise Figure	10.51 dB

[1] The manufacturers data sheet of measured performance specified a noise figure for the amplifier of 1.6 dB. As part of the acceptance of the amplifier, the noise figure was measured by C.R.C. personnel. Our measured value was 1.9 dB. For the theoretical calculation, the larger of these two values was used as the amplifier's noise figure.

The theoretical noise figure was then determined to be 10.51 dB.

The system noise figure was then experimentally evaluated using the following formula:

$$N.F. = \frac{C}{N_{in}} - \frac{C}{N_{out}} \qquad (1)$$

The carrier to input noise ratio, C/N_{in}, was measured as the ratio of the input power to the free space background noise of a room temperature environment. Eqn. 2 gives the relation used:

$$\frac{C}{N_{in}} = P_{in} - kTB \qquad (2)$$

The input power P_{in} was nominally set to -80 dBm. The noise power, kTB, was measured over a bandwidth of 1 Hz at a temperature of 290°K. With $k = 1.3806*10^{-23}$ J/K, $kTB = 4.00374*10^{-21}$ watts or -173.97 dBm. Consequently, C/N_{in} was taken as 94 dB.

The carrier to output noise C/N_{out}, was determined by using the built-in noise level functions of the HP spectrum analyzer. Measurements were done at both the 70 MHz IF point (immediately after the K&L B114 filter) as well as at the 20 MHz output. Figs. 8 and 9 show the spectrum of the signals at both locations. In both cases P_{in} was set at -80 dBm. In Fig. 8, the 70 MHz carrier had a power of -34.7 dBm, while the noise spectral density N_o, in a 1Hz bandwidth, was at -117.2 dBmHz. C/N_o at 70 MHz is then measured to be 82.5 dBHz. At the 20 MHz point, the carrier power was +16.7 dB while the noise spectral density was at -65.7 dBmHz. C/N_o at the 20 MHz point is measured to be 82.3 dBHz. It is interesting to note that the C/N_o is the same for both frequencies at their respective system bandwidth.

Using the experimental values, the measured system noise figure was found to be:

$$N.F. = \frac{C}{N_{in}} - \frac{C}{N_{out}} = 94\ dBHz - 82.3\ dBHz = 11.7 dB \qquad (3)$$

Table 2: Theoretical and experimental system noise figure

Theoretical	10.51 dB
Experimental	11.7 dB

The discrepancy between the theoretical and the experimental values may come from the addition of average values provided by the manufacturers, or by estimation errors due to the HP spectrum analyzer.

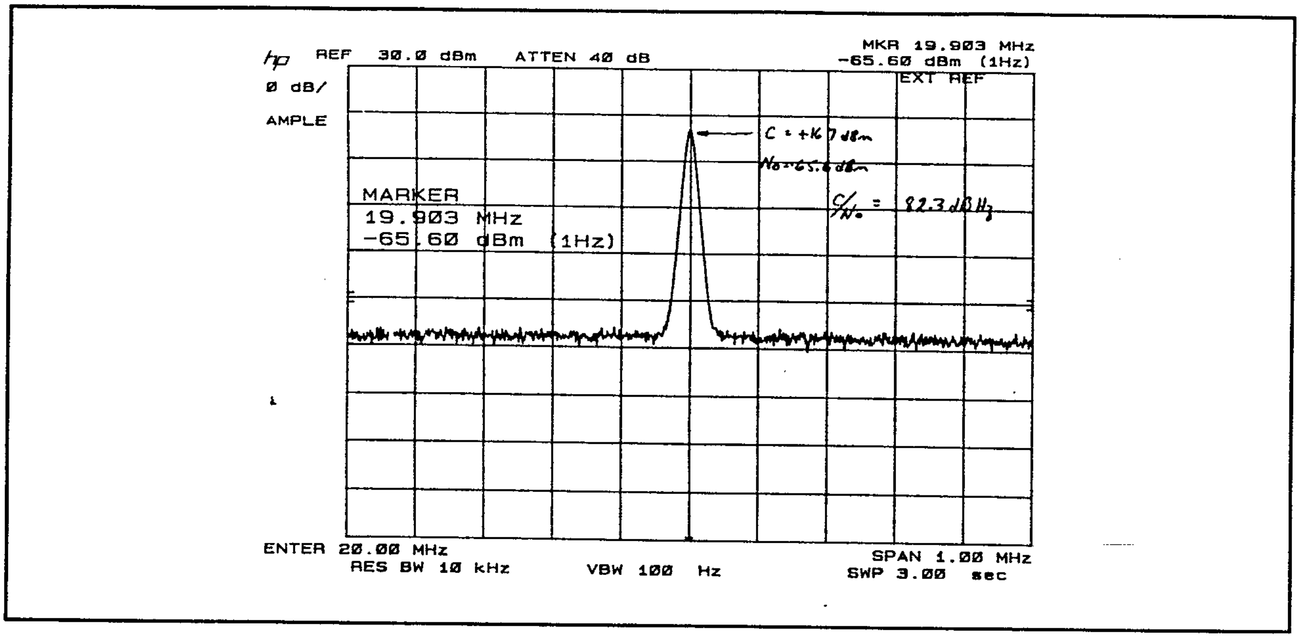

Figure 8 Spectrum analyzer plot of the signal at the output.

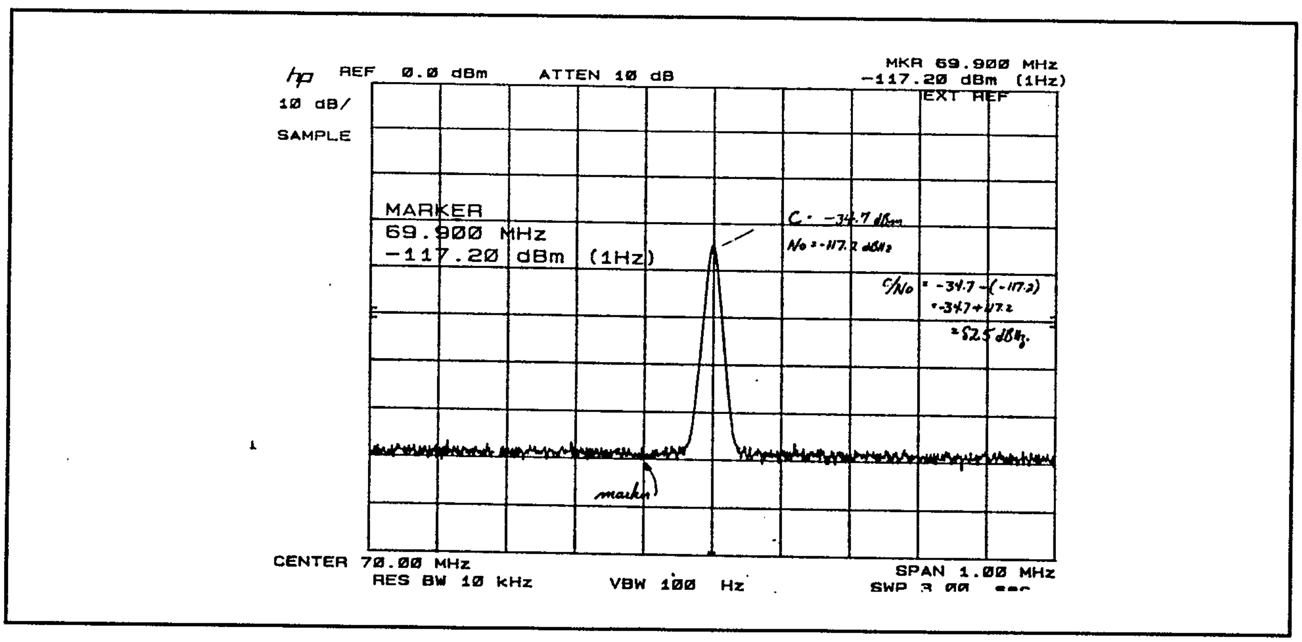

Figure 9 Spectrum analyzer plot of the signal at the 70 MHz point (after the filter)

5.0 ONE dB COMPRESSION POINT

The 1dB compression point was measured at the 70 MHz point (after the filter) and at 20 MHz (system output). The technique used for this measurement was simply to vary the 44 GHz input signal with the calibrated attenuators, and to measure the resulting down converted signal. Figs. 10 and 11 show the resulting curves at the 70 MHz and 20 MHz points. The horizontal represents the 44.5 GHz input power level while the vertical corresponds to the down converted signal power level.

It can be seen that the 1 dB compression point for the 70 MHz is around 22 dBm (Fig.10) while this point is at 19 dBm at the 20 MHz system output (Fig.11). This agrees with the catalog data for the Anzac AM-110 amplifier which is the last active stage before the measurement points. The catalog data was +21 dBm minimum.

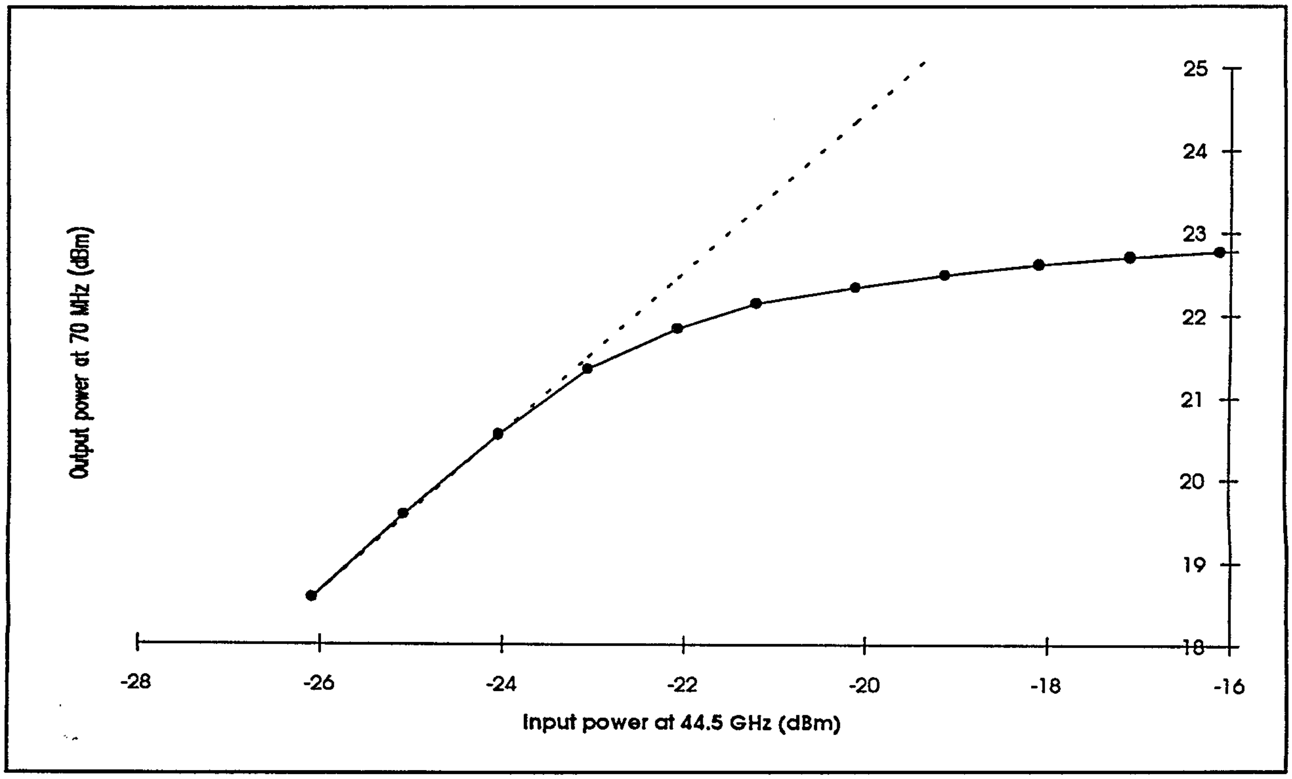

Figure 10 1 dB compression point at the 70 MHz point: 22 dBm

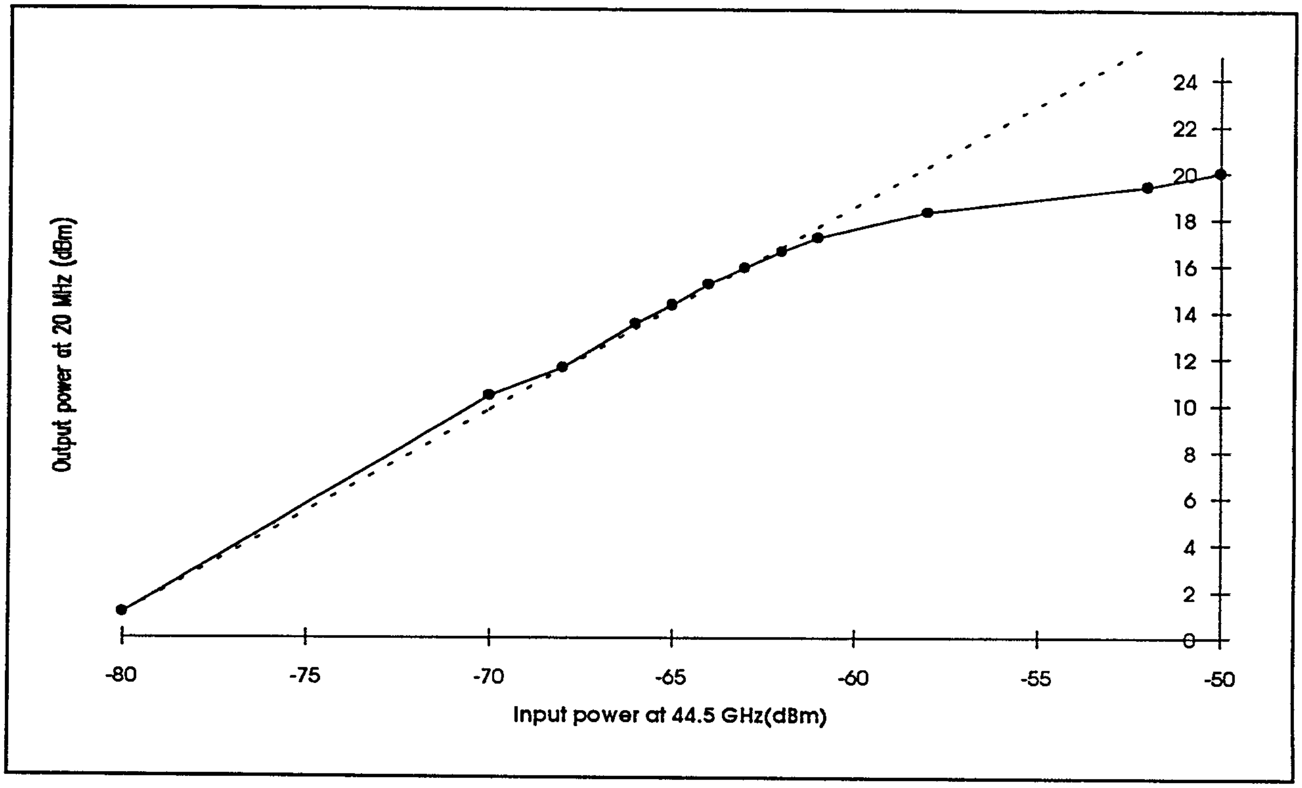

Figure 11 1 dB compression point at the 20 MHz point: 19 dBm

6.0 TWO-TONE INTERMODULATION PRODUCT

Fig. 12 shows the set-up used to perform the two-tone intermodulation product test. Two HP 8673 synthesized signal generators were used as the two tone generators. As with the single tone system (Chap 2), the generators were set up to produce a frequency between 14.5 GHz and 15.16 GHz. Each generator was connected to a waveguide tripler, to produce signals in the 43.5 to 45.5 GHz range, and a variable waveguide attenuator. The power level in the triplers were 0dBm in the WJ1204 and +10 dBm in the WJ2300N, as specified by the manufacturer. The following attenuators allowed independent control of the output level of each signal. Both of those signals were adjusted such that they had equal power.

The attenuator outputs were summed together in a Hughes 45582H Hybrid Tee. To electrically isolate the two generators, one generator was connected to the E arm, and the other generator was connected to the H arm. As the Tee is a 4-port device, one of the two remaining ports was terminated with a waveguide termination, while the last port was used as the output port. The output signal was then passed through the Gamma-F waveguide filter, a Hughes waveguide isolator and the three rotary vane attenuators. Power levels from -80 dBm to -50 dBm were used as the input of the down converter.

Four different sets of frequency spacing between the two generators were selected for this two-tone intermodulation test. The four tone separations were 10 kHz, 45 kHz, 98 kHz and 200 kHz. The 20 MHz down converter output signal was then connected to the spectrum analyzer. From the four sets of data, it was observed that tone spacing had minimal effect on the intermodulation generation. The graph shown in Fig. 13 reflects the data taken from the 10kHz spacing. Also included in this graph are the output power of the 20 MHz signal (data taken from Fig.11). The two-tone intercept point is found at the interception of the two asymptotes, i.e. +27 dBm.

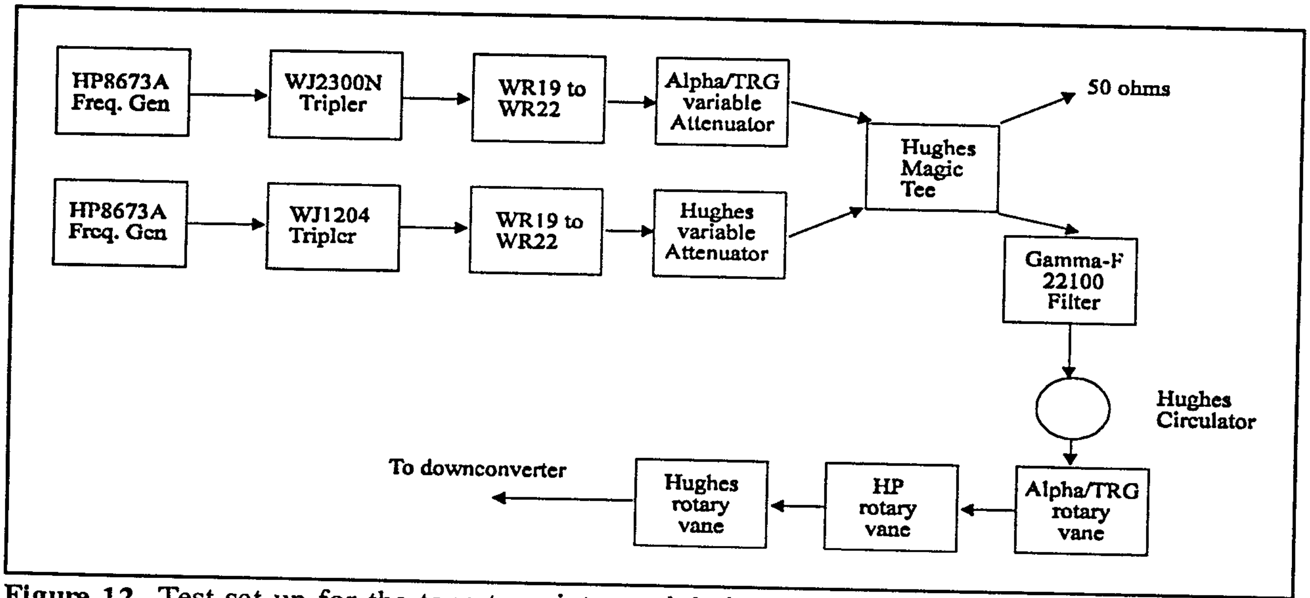

Figure 12 Test set-up for the tone-tone intermodulation product.

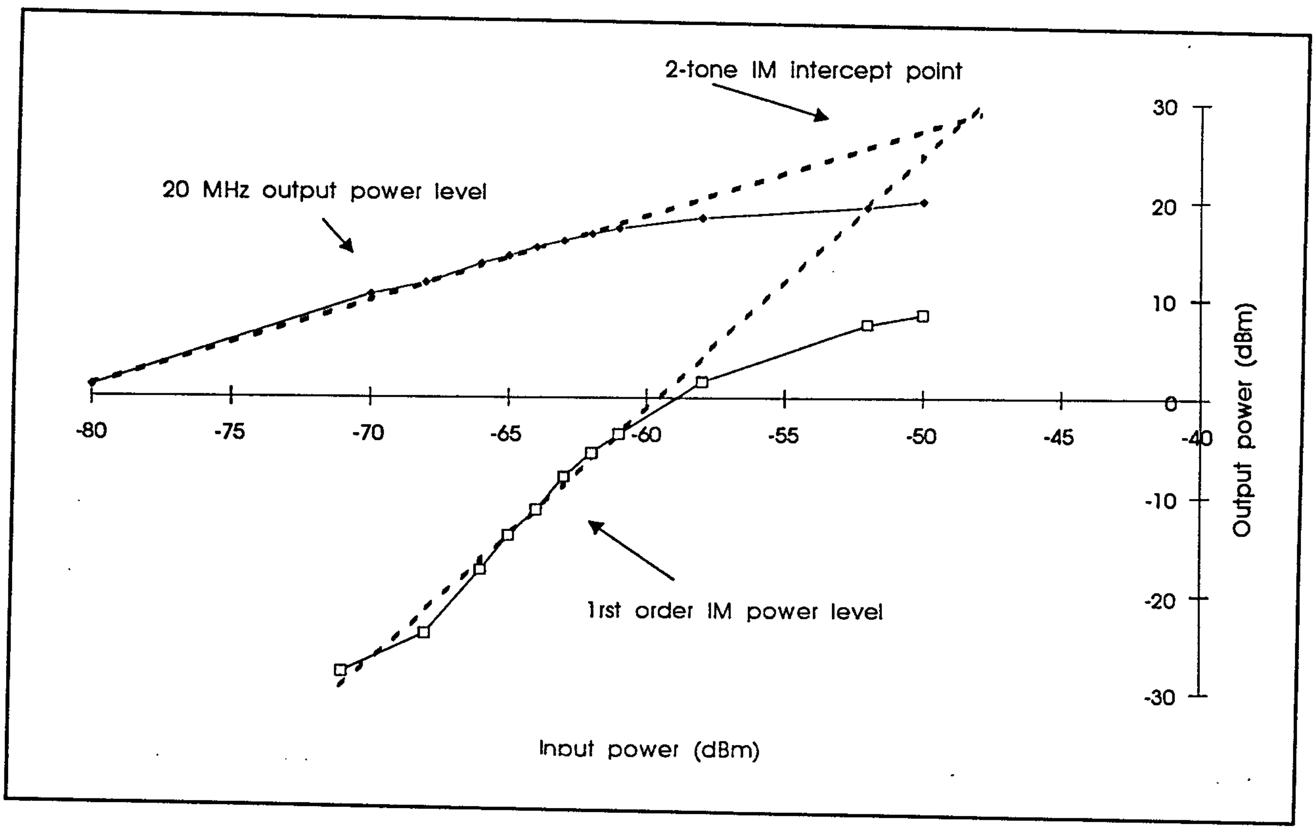

Figure 13 Two-tone intermodulation product (10kHz spacing). Also included is the data from Fig. 10 for the 20 MHz 1dB compression point to obtain to 3rd order intermodulation point.

7.0 LINEARITY MEASUREMENTS

In this test, the linearity of the 20 MHz output power, as a function of the input frequency, is evaluated. The 43.5 to 45.5 GHz input frequencies were provided by the frequency source test bed described in Chap 3, Fig. 5. while the 6-8 GHz dehopping source was described in Fig. 6.

In order to evaluate the linearity of the down converter, the power level of the input signal had to be maintained constant for every input frequency from 43.5 to 45.5 GHz. The input power was maintained at -80 dBm by monitoring the power meter placed in the source circuit (Fig.5). The power meter reading was maintained at -20 dBm for every frequency by using a variable attenuator. Two more attenuators provided the rest of the attenuation to -80 dBm. The attenuators and the directional coupler frequency responses were measured to be flat within ±0.5 dB.

With the coupled RF power level maintained at -20 dBm, the input frequency was varied, in steps, from 43.5 to 45.5 GHz. The input RF power level could fluctuate within ±0.5 dB due to the linearity of the attenuators and the directional coupler. The 20 MHz output power was monitored on a spectrum analyzer and is shown in Fig. 14.

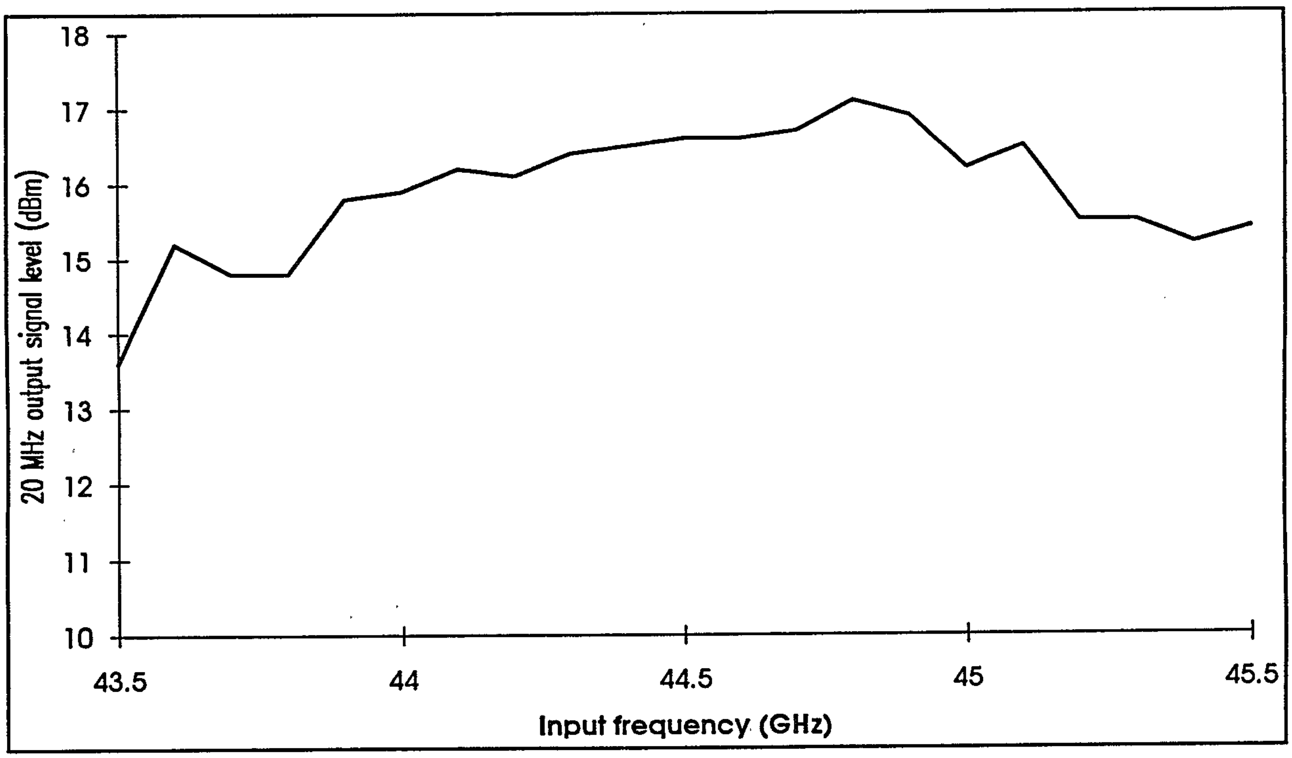

Figure 14 Linearity of the 20 MHz output spectrum of the down converter unit as a function of the input frequency.

8.0 CONCLUSION

A frequency down conversion unit has been designed, assembled and tested as part of the D6470 in-house payload simulator. The down converter unit translates an incoming RF frequency hopping signal, from a 43.5 to 45.5 GHz band to a dehopped 20 MHz signal.

The achieved specifications for the unit are:

Input frequency band:	43.5 GHz to 45.5 frequency hopped signal
Output signal frequency:	20 MHz dehopped
Gain	80 dB
Noise figure:	11.7 dB
1 dB compression point:	19 dBm
Linearity:	±1.5 dB over 2 GHz bandwidth

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RÉSUMÉ

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