DESIGN OF A HIGH POWER EARTH STATION TRANSMITTER FOR THE BAND 7.9 to 8.4 GHz

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ABSTRACT

Three 10 KW klystrons are combined to cover the full 7.9 to 8.4 GHz band using a triplexer with less than 0.5 dB loss. A novel asymmetrical notch filter allows the severe IM specification to be met.

Introduction

This paper describes the design of a high power earth station transmitter for the band 7.9 to 8.4 GHz. The key to the design is the use of a contiguous channel triplexer as the high power combiner. This, in conjunction with a novel asymmetrical notch filter allows the very severe intermodulation specification to be met. The total loss between the klystron output flange and the antenna is less than 1.9 dB at band centre.

Transmitter Specifications

The requirement specification recommended the use of Varian VKX7799B klystrons for the high power amplifiers. These tubes have a 1 dB instantaneous bandwidth of 175 MHz and a single carrier saturated output power of 10 KW. It was required that the transmitter should operate at any frequency in the band 7.9 to 8.4 GHz, and this meant that three klystrons, each one covering one-third of the band had to be used. Further, provision had to be made for connecting a fourth hot-standby HPA at a later date.

The required transmitter single carrier output power was 5 KW per HPA, and this meant that the total loss between each klystron output flange and the transmitter output had to be less than 3 dB. A further requirement was that the level of any intermodulation product in the band 7.25 to 7.75 GHz at the transmitter output had to be less than -120 dBm for two-carrier operation up to maximum HPA output power. This is equivalent to C/I_3 ratio of 183 dB and demonstrates the severity of the filtering requirements.

COMBINER	Loss, dB	
	Coupled 4th port	Switched 4th port
PASSIVE	6.0	4.75
FILTER/CIRCULATOR	5.0	3.35
HYBRID/FILTER	4.9	3.2
CONTIGUOUS CHANNEL TRIPLEXER	3.3	0.5

Table 1. Losses associated with different combining techniques

Design of Transmitter

A number of combining techniques were studied in detail, and their performance in terms of loss is summarised in Table 1. The contiguous channel multiplexer (a triplexer in this case) offers by far the lowest transmission loss (< 0.5 dB) across the band 7.9 to 8.4 GHz, except at frequencies very close to the crossover frequencies. In addition, the inherent selectivity of the triplexer greatly relaxes the selectivity required of the transmit filter. If a hybrid/filter or a circulator/filter combiner were to be used then the selectivity required of the transmit filter would result in an unacceptably high passband insertion loss.

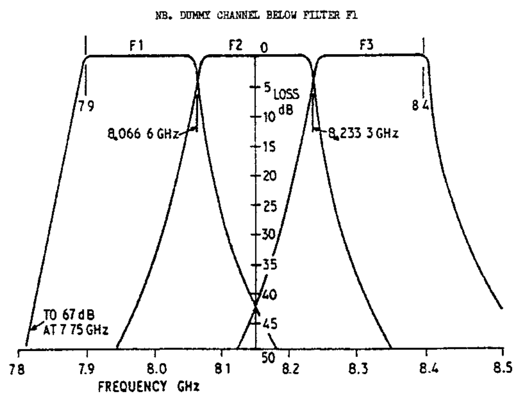

Fig.1 Amplitude Response of Triplexer

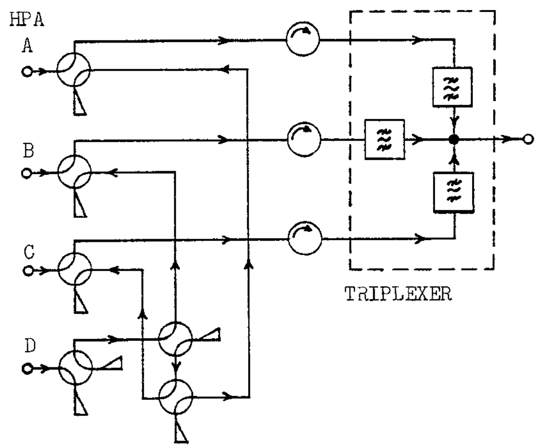

Fig.2 Combiner Configuration

The amplitude characteristics of the triplexer are shown in Fig. 1, while the chosen combiner configuration is shown in Fig. 2. The isolators at the triplexer inputs are normally part of the HPA subsystem, but have been positioned as shown to provide a good input match to the triplexer at all times, particularly when the hot-spare klystron is switched in. A momentary mismatch at, say; filter F2 input (during operation of switch SB) would momentarily distort the amplitude and group delay characteristics near to the crossover frequencies of filters F1 and F3. This could result in unacceptable distortion or even an outage for accesses close to the crossover frequencies in bands F1 and F3.

The triplexer consists of three bandpass filters connected to a common output manifold. Each branch of the triplexer is a 5 element direct-coupled cavity chebyshev filter. Every element of each filter is modified to take into account the interaction of the other filters at the manifold. The result is that for a given value of insertion loss the inter-channel selectivity of the filters is far better than would be obtained for an identical filter operating alone. Typically, a single filter having its 20 dB point at some frequency has its 35 dB point at the same frequency when it is incorporated into a properly designed multiplexer, and the insertion loss is the same. The same selectivity enhancement can be obtained on the lower skirt of filter F1 by incorporating a 2-element dummy channel with a passband below F1. This technique is employed here and gives the results shown in Fig. 1.

The behaviour close to the crossover frequencies is shown in Fig.3, where it can be seen that the loss exceeds 1 dB over only a 10 MHz band. This was acceptable in this case.

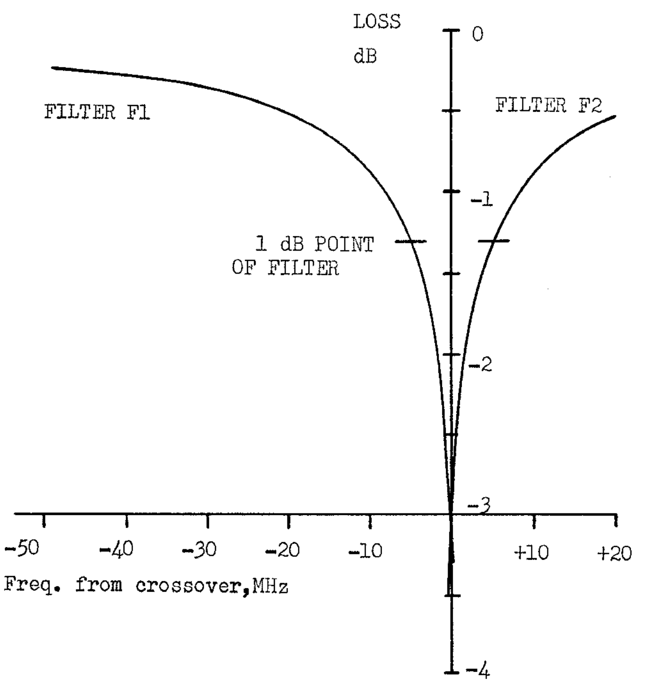

Fig. 3 Triplexer Crossover Performance

One advantage of using the triplexer is that its transmission loss at second harmonic frequencies exceeds 50 dB. Separate harmonic filters are therefore not needed in the HPA subsystem, and this saves both the cost and the insertion loss associated with such filters.

In order to tolerate the power levels involved the triplexer has to be pressurised with SF_6 and liquid-cooled. The breakdown power across the passbands has been calculated at 71 KW per branch. At the crossover frequencies the breakdown power is 24 KW per branch which is three times that required, giving an adequate safety margin.

1 Order of IM product	**3**	**5**	**7**	**9**	
2 Frequency range in which product can fall	7.733 -7.75	7.567 -7.75	7.4 -7.75	7.25 -7.75	GHz
3 C/I ratio at maximum output power per carrier	13.6	30.0	≈ 40	≈55	dB
4 Single carrier saturated output power	40	40	40	40	dBW
5 Output back-off per carrier at 2-carrier saturation	4.6	4.6	4.6	4.6	dBW
6 Power of IM product (=4-5-3)	21.8	5.4	-4.6	-19.6	dBW
7 Attenuation needed to meet specification of -150 dBW	171.8	155.4	145.4	130.4	dB

Table 2. Derivation of Attenuation Required to meet the Receive Band IM Specification.

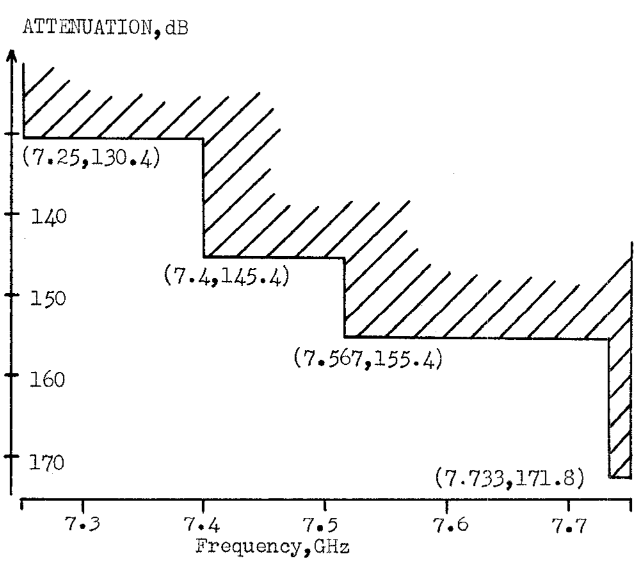

Fig.4 Attenuation Required to Meet Receive Band Intermodulation Specification

The attenuation required to meet the intermodulation specification in the receive band is derived in Table 2, and the resulting mask is shown in Fig. 4.

When the attenuation of the triplexer is taken into account the remaining additional attenuation to be provided is as shown in Fig. 5. Also shown in Fig. 5 are the characteristics of a suitable 7th order asymmetrical notch filter which will provide the required attenuation. The main advantage of this novel type of filter is that its loss at 7.9 GHz is only 0.3 dB and rapidly drops to about 0.1 dB at higher frequencies in the transmit band.

This type of filter has only recently been developed and a 5th order version in WG14 has demonstrated performance remarkably close to the design characteristics. Power handling is not a problem from a breakdown point of view. The filter is constructed from a length of waveguide with seven short cavities mounted perpendicular to the broad wall. Coupling from the straight-through waveguide into the cavities is achieved via capacitive irises which only couple power in the band 7.25 to 7.75 GHz as demonstrated by Fig. 5. In the transmit band the filter appears simply as a length of waveguide.

The specification of 105 dB attenuation has only to be met when the HPA's are operated close to saturation, and in this case the filter will be running hot. The notch filter is therefore designed to meet the required specification at this temperature.

A block diagram of the whole transmitter is shown in Fig. 6. Switches S1 to S3 give flexibility in the upconverter/HPA routing, while switches S4 to S6 and SA to SF control the redundancy switching of HPAD, which incorporates an automatic channel tuner. Switches SR and SL permit remote calibration and zeroing of the EIRP monitor under computer control, while SG and C4 allow reduced EIRP operation at a good carrier to noise ratio for testing/calibration purposes.

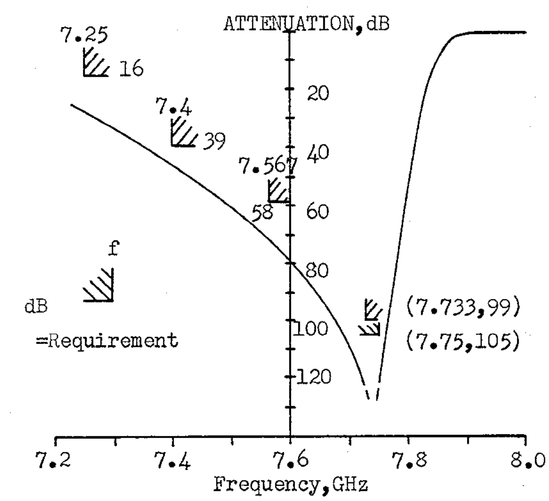

Fig. 5 Characteristics of Seventh Order Asymmetrical Notch Filter

The loss from a klystron flange to the antenna interface is only 1.9 dB, except at frequencies very close to the crossover frequencies. The loss at crossover is about 4.5 dB, while the 3 dB output loss specification is exceeded only in two 10 MHz bands centred on the crossover frequencies.

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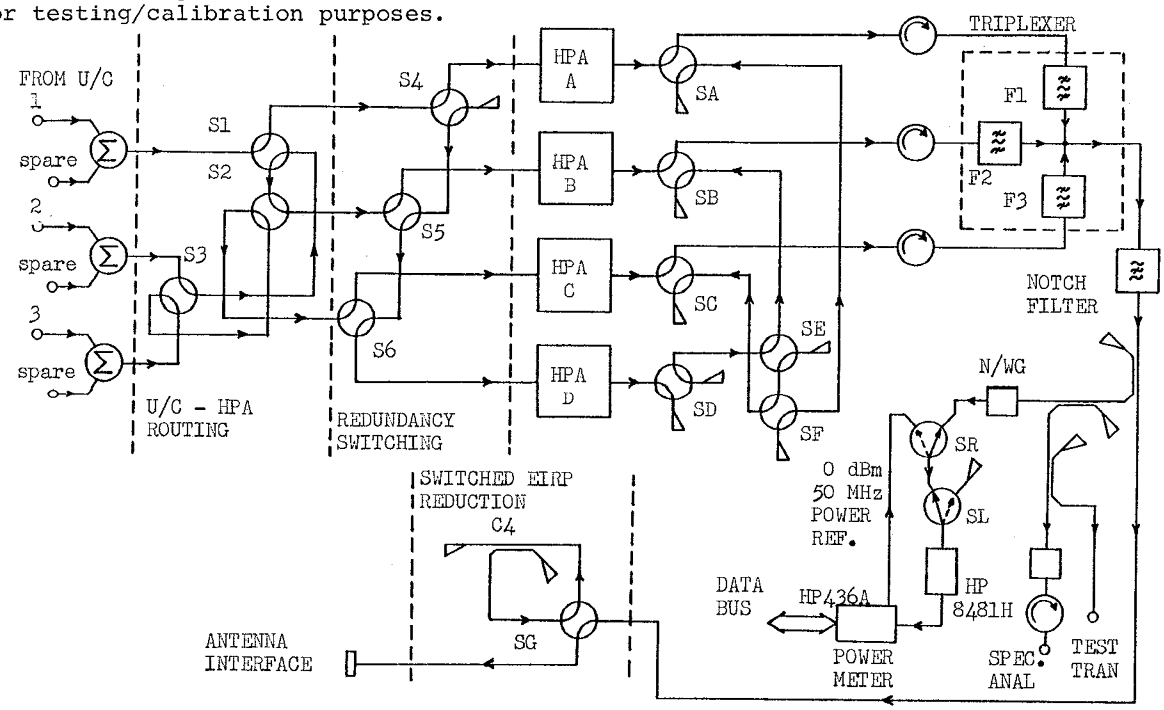

Fig. 6 Transmitter Block Diagram