AT File

Holography Instrumentation

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1 Preamble

In order to determine the accuracy of the antennas at Parkes, Mopra and Narrabri, holography techniques are used. The complex (amplitude and phase) beam patterns of the antenna under test are obtained using a strong remote signal source. The source could be an astronomical object (eg, a water vapour maser), or a beacon on a geostationary satellite.

A phase reference is needed in order to measure the complex pattern; the usual practice is to set up a reference antenna which is kept pointing at the signal source.

The Stanford Research Systems SR830 DSP Lock-In amplifier would be suitable as the device to measure the relative phase. However, since its maximum input frequency is only 102 kHz, some downconversion operation is required. This note describes a possible solution.

2 Received Power from a Satellite

Some possible beacons are :

- Intelsat VII. This has a beacon at 3950 MHz, in vertical polarisation, with a minimum EIRP of +4 dBW.

  (EIRP is the effective isotropic radiated power).

  Since the expected maximum EIRP is 7 dB above the minimum EIRP, the power will lie in the range +4 to +11 dBW; we use 4 dBW for the calculations, but note that 10 dBW is a more realistic value.
- Optus (Aussat) B1 and B3. These have a beacon at 12750 MHz, and an EIRP of +10 dBW (+/- 1 dB), linear polarisation, horizontal and vertical. There are two feedhorns some distance apart, leading to elliptical polarisation.
- Optus B3 also has a beacon at 30.44 GHz, horizontal, vertical or switched at 1 kHz. It is usually left fixed to one polarisation. The EIRP is 13.5 dBW.

The power received by an antenna of diameter D is :

Table 1: Intelsat VII - 3.95 GHz beacon at +4 dBW EIRP

	Antenna Diameter (m)			
	1.2m	4.5m	22m	64m
Received Beacon Power (dBm)	-129	-118	-104	-95
Antenna System temperature (K)	50	50	50	50
Noise Power Spectral Density (dBm/kHz)	-152	-152	-152	-152
Beacon Power above System Temperature				
(a) 1 kHz Bandwidth (dB)	23	34	48	57
(b) 10 kHz Bandwidth (dB)	13	24	38	47
Estimated Satellite Noise Floor (dBm/kHz)	-169	-158	-144	-135

Table 2: Optus B1. B3 - 12.75 Beacon at +10 dBW EIRP

	Antenna Diameter (m)			
	1.2m	4.5m	22m	64m
Received Beacon Power (dBm)	-123	-112	-99	-89
Antenna System temperature (K)	120	120	120	120
Noise Power Spectral Density (dBm/kHz)	-148	-148	-148	-148
Beacon Power above System Temperature				
(a) 1 kHz Bandwidth (dB)	25	36	49	59
(b) 10 kHz Bandwidth (dB)	15	26	39	49
Estimated Satellite Noise Floor (dBm/kHz)	-163	-152	-139	-129

$$P = \eta \frac{EIRP}{4\pi R^2} \pi D^2 / 4$$

where R is the distance to the satellite, roughly 36000 km for the satellites of interest; η is the antenna efficiency.

Table 1, 2 and 3 lists the power from our satellite candidates, for several different antenna diameters.

Notes

1. (3.95 GHz) It would be difficult to lock a 1.2m antenna to the beacon if the bandwidth is set to 100 kHz; even 10 kHz would be unsatisfactory, as there would be jitter on the signal.
2. (3.95 GHz) A 4.5m antenna would be a satisfactory reference antenna. The signal to noise ratio is adequate, even at 10 kHz bandwidth. The noise is still dominated by the frontend and not the noise from the satellite.
3. (12.75 GHz) It would be possible to get the 1.2m antenna to lock.
4. (12.75 GHz) Many years ago we locked the Scientific Atlanta receiver onto this beacon with a filter bandwidth of 100 kHz, and a 1.5m antenna; it was very sensitive, losing lock when the antenna moved and the effective gain dropped slightly
5. (30 GHz) Although the beacon power received by the antenna is higher than for the other beacons, the receiver temperature is much higher. The beacon power is expected to be only

Table 3: Optus B3 - 30.44 GHz beacon at +13.5 dBW EIRP

	Antenna Diameter (m)			
	1.2m	4.5m	22m	64m
Received Beacon Power (dBm)	-120	-xxx	-95	-xx
Antenna System temperature (K)	250	250	250	250
(2.5 dB noise figure)				
Noise Power Spectral Density (dBm/kHz)	-145	-145	-145	-145
Beacon Power above System Temperature				
(a) 1 kHz Bandwidth (dB)	25	xx	50	xx
(b) 10 kHz Bandwidth (dB)	15	xx	40	xx
Estimated Satellite Noise Floor (dBm/kHz)				

about 15 dB above the system noise for a 10 kHz bandwidth with the 1.2m antenna. A narrower bandwidth of 4 kHz would increase this to 21 dB. There should be no significant problems locking onto the beacon. The bandwidth of the filter in the phase lock circuit is important for robust locking onto the beacon.

2.1 Frontend Bandwidth

When using the 4.5m diameter antenna as a reference, the 12.75 GHz beacon signal would be about 4 dB below the IF noise power due to the receiver system for a 10 MHz bandwidth.

With a wider IF bandwidth (say, 100 MHz) the satellite transmissions may be within the band. These would have very much higher power levels than the beacon.

Therefore, it would probably be wise to limit the frontend bandwidth to 10 MHz before the signal is applied to the backend conversion system.

A wider bandwidth would probably require extra gain (say 20 dB) after the narrow bandwidth filters.

3 A Possible Block Diagram

We need to convert down from the region 70-140 MHz to about 50 kHz, with selectable bandwidths down to a few kHz. It is desirable that any images within the conversion be suppressed by filtering or by using image rejection mixers. On some satellites there are other strong signals 1 MHz from the beacon. As simple filtering is not possible, image reject mixers could be used, using commercial components, to attenuate the image band.

To reduce the noise bandwidth from the receiving system of the antennas (both the target and reference antennas), ceramic filters, centred on 455 kHz may be used. These typically have about 60 dB attenuation in the stop band, with some spurious responses at 45 dB in the band to 1 MHz.

As the Stamford Research Systems SR830 DSP Lock-in amplifier has a frequency input band of 1 mHz to 102 kHz, another fixed conversion will be required to mix 455 kHz down - to (say) 45 kHz.

Additional design considerations.

The whole purpose of this equipment is to measure the complex beam pattern - so we will be measuring the amplitude and phase of the signal from the target antenna, with the reference antenna providing

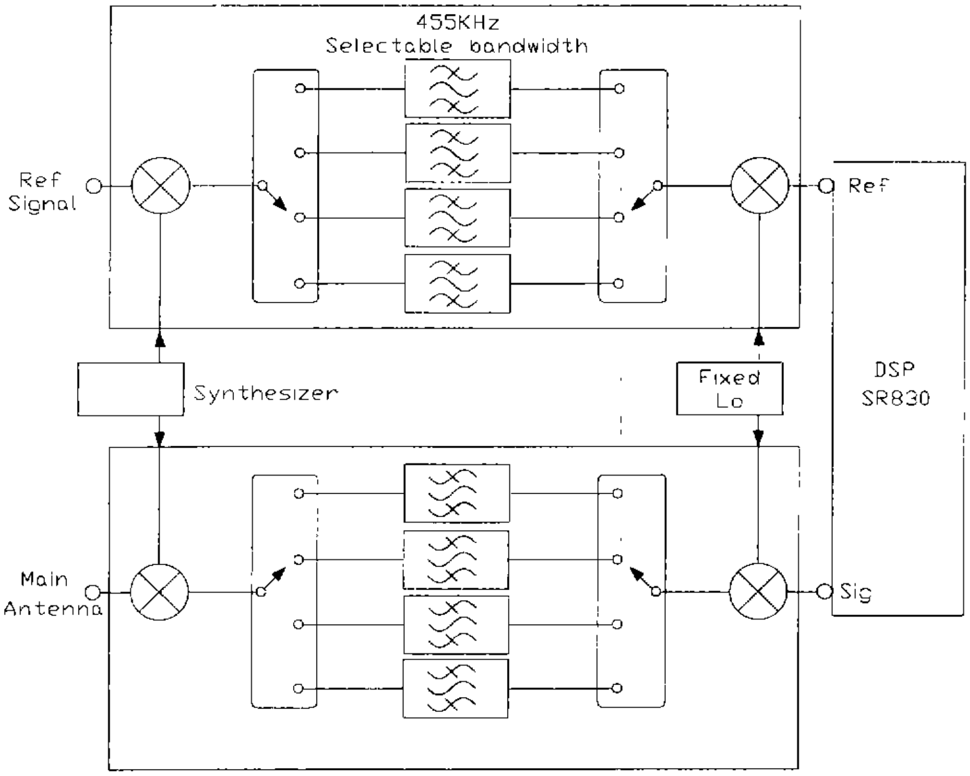


Figure 1: Overall block diagram

both phase and amplitude reference. The lock-in amplifier does allow us to recover the amplitude of the reference signal, so the measurement side of the problem is addressed. However, we need to be sure that the measured quantities are honest.

Some method of determining the system gain (from antenna to the input to the SR830) is needed. Although we could install some form of noise injection calibration, this is probably unnecessary as the electronics are likely to be stable on time scales of 10 minutes or so. In other words, we can calibrate the system performance by making boresight calibration observations at regular intervals - at the end of every scan, for example. We make this assumption for both amplitude and phase.

3.1 Beacon Frequency Drift

It is known that the beacon frequency can drift - the beacons are most likely to be free-running crystal oscillators. For the Intelsat VII (the only beacon for which we have detailed information) the stability is quoted as +/- 40 KHz for all in-orbit operating conditions, over the satellite design lifetime.

The stability over one day is +/- 4 KHz, and the short-term stability is such that 90% of the EIRP is within a 5 Hz bandwidth around the centre frequency. (Therefore the long term stability is 10^{-5} and the stability over one day is 10^{-6}).

1. Regular boresight calibration will be required since the narrow bandwidth filters have a steep transmission phase/frequency characteristic.

Note that a calibration is usually performed at the end of each scan in order to reduce any baseline calibration problems. Therefore we need to consider the phase stability of the system over time scales of just a few minutes. Within this time the beacon frequency is likely to change slowly, probably no more than 20 Hz. This corresponds to a frequency change of 0.4% of a 5 KHz bandwidth.

The absolute phase characteristic can be calculated from the Group Delay Time:

$$T = \frac{-d\phi}{d\omega}$$

where ϕ is the phase (radians)
ω is the frequency (radians/sec)
T is the Group Delay Time (secs)

This leads to an absolute transmission phase change of about 2 degrees (for our estimated frequency drift) for a 5 KHz bandwidth ceramic filter centred on 455 KHz. The relative phase change between two filters, one in the reference path, the other in the target antenna path, is thus likely to be very small.

2. Some tuning could be required to keep the signal within the narrow band filters (10 KHz or less).

The SR830 seems able to provide a computer-readable measure of the frequency of the synthesiser phase-locked to the reference channel. This frequency could be used to retune the conversion chain, maintaining a fixed frequency at the input to the SR830, see figure 2.

If the reference frequency drift exceeds some threshold (say more than 1 KHz) the external synthesiser could have its frequency adjusted to move the reference signal back to the nominal value. This retuning would only be done during the boresight calibration stage.

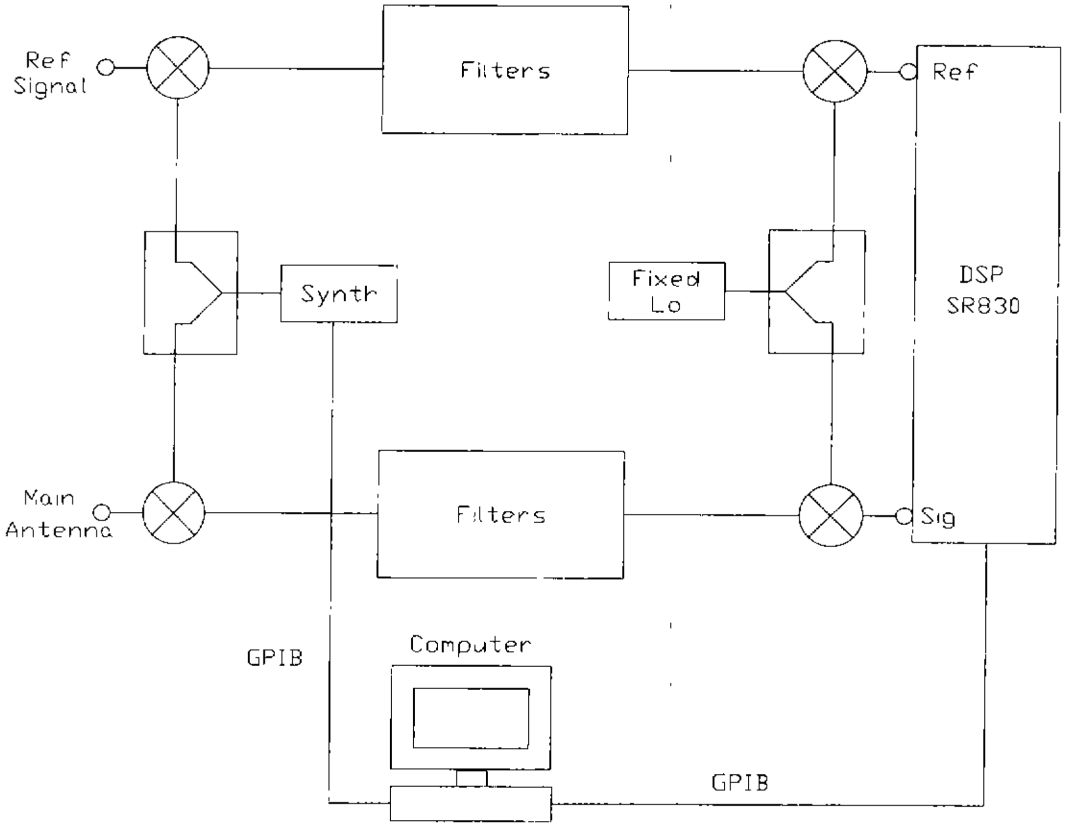


Figure 2: Revised block diagram with the feedback loop to provide the frequency tracking

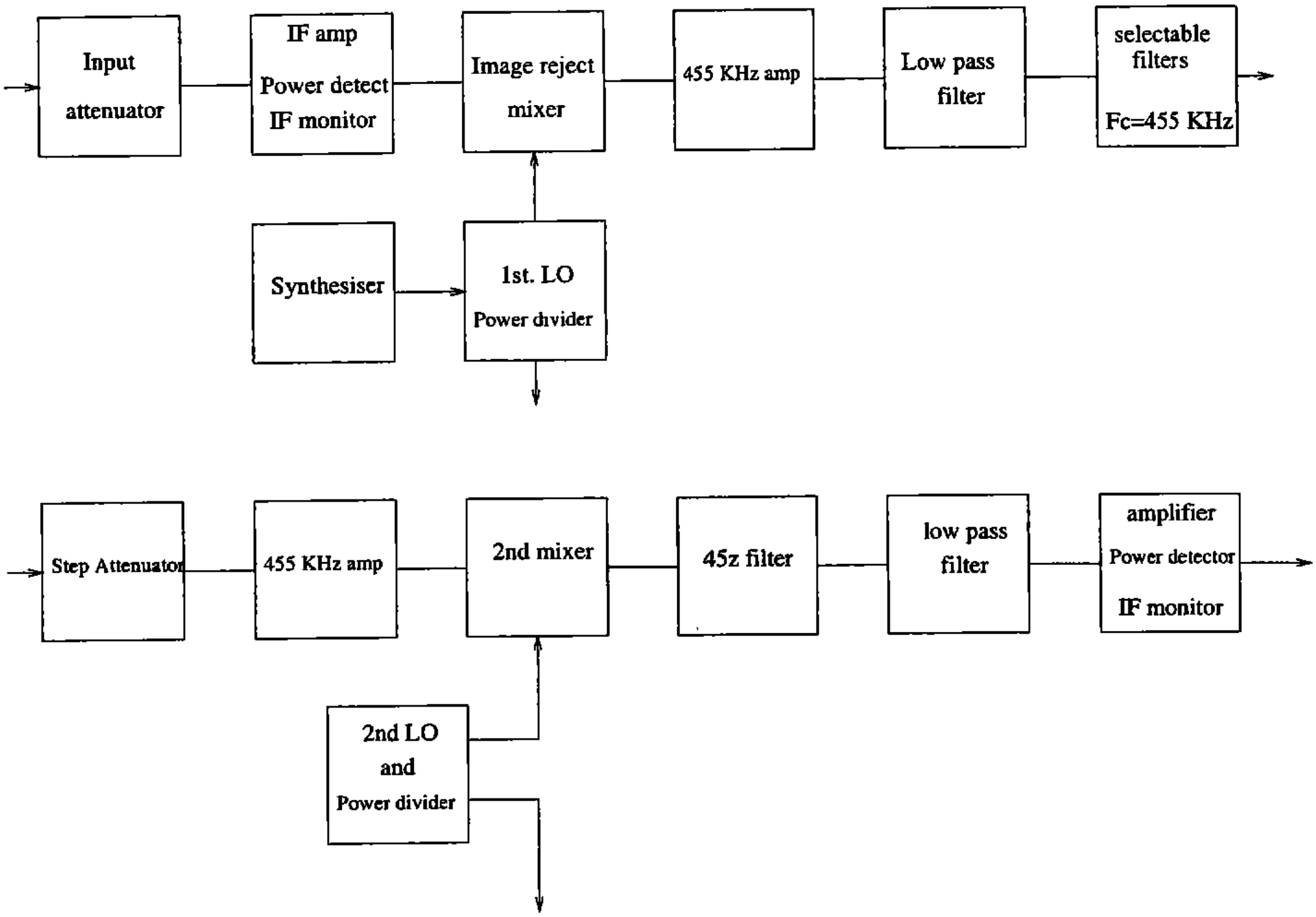


Figure 3: Detailed block diagram

4 Circuit Possibilities

4.1 Detailed Block Diagram

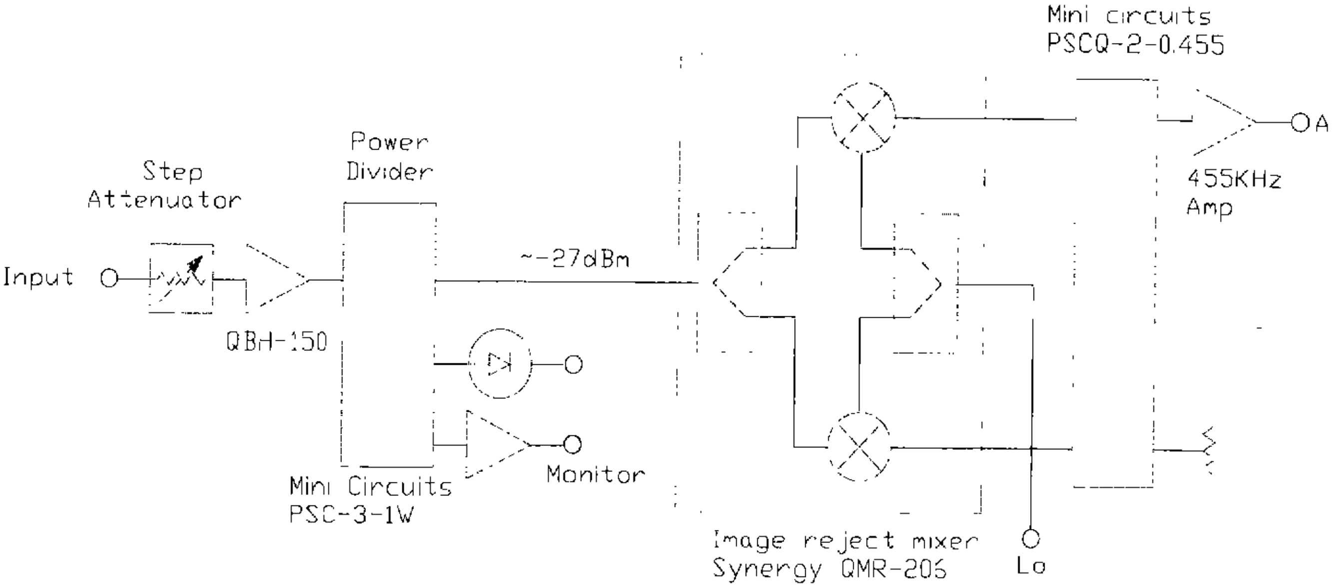
Broad specifications :

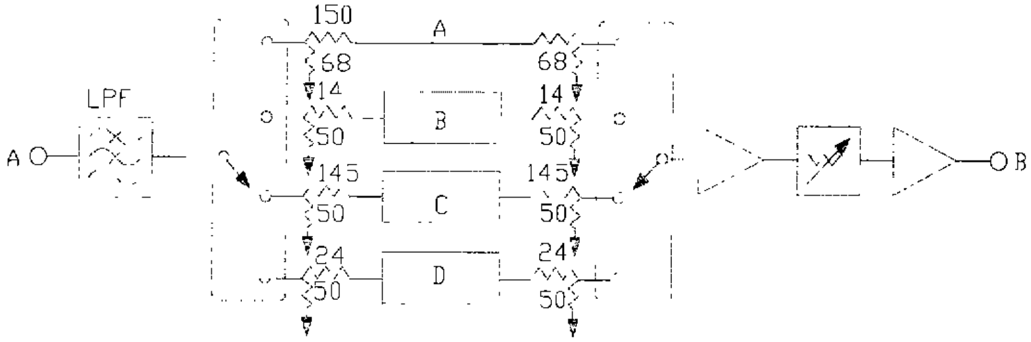
Input Frequency Range	70 MHz to 160 MHz
Input Power	-40 dBm minimum -10 dBm maximum
Output Frequency	45 kHz
Output Power	say 0 dBm

4.2 Input Attenuator

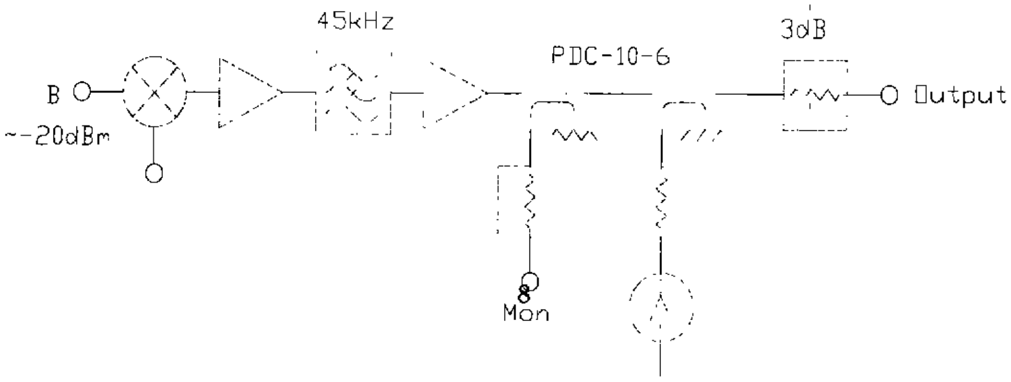
A mechanical step attenuator could be used here. They do tend to be fairly large and expensive. I would prefer not to use a continuously variable attenuator. A step unit would have better loss stability.

As an alternative to a mechanical unit one could use a GaAs step attenuator. For example the AT-260 attenuator by M/A-Com would be suitable. Its specifications are : Dc to 2 GHz; 31 dB range in 1





B:-CFC455AG2
C:-CFM455E
D:-CFM455I



dB steps; low-cost SSOP package; P(1dBm) is +20 dBm; VSWR is typically 1.6, although the data sheet graphs suggest 1.4.

4.3 IF amplifier, Power Detector, IF monitor

A Q-bit amplifier, QBH-150 would be suitable. These have very stable gain/temperature characteristics and excellent input & output match.

It would be useful to measure the input power after a suitable attenuator. We have used some back (tunnel) diodes (model A1X618 from TRW microwave). These have good square-law characteristics and are very stable to temperature changes.

It is also desirable to run a sample of the signal to the front panel so that it could be measured with a spectrum analyser.

4.4 Image Reject Mixer

I have not found a commercial image reject mixer with the IF at 455 kHz. All the units seen have IFs at 10 MHz or higher. This means that we are on our own.

A quadrature IF mixer, from Synergy (QMR-206) may be suitable, followed by a 90 degree hybrid from Mini-Circuits (PSCQ-2-0.455). The 1 dB compression point on the input is only +3 dBm (minimum) for this mixer. This is not very high, but typical for the given LO power. Probably run the signal at typically 30 dB below this P(1 dB). Intermodulation products should not then be a problem. Make the maximum input power about 10 dB above this value.

With an amplitude imbalance of typically 0.6 dB from the mixer, 1.2 max imbalance from the hybrid, the image rejection may be only 18 dB (worst case) for a 100 kHz bandwidth. At the centre of the band (0.455 kHz) the image may be suppressed by more than 30 dB.

It may be possible to purchase or design a hybrid with better phase and amplitude characteristics. The image rejection would then be better over the full 100 KHz band.

4.5 455 kHz Amplifier

(Some uncertainty here).

Perhaps a Mini-Circuits MAV-4 amplifier, or equivalent.

Alternatively, use two transistors with feedback. As +/- 15V would be available (we need to run some operational amplifiers for the detectors) the emitter resistor (to - 15V) may hold the collector currents with little variation. The amplifiers would then have very stable gain.

It may also be possible to use an operational amplifier. Its input noise may be a problem at this part of the circuit.

4.6 Low-Pass Filter

Something like a third or fifth-order Tchybycheff filter with a corner frequency of 1 MHz. A standard L-C one, or possibly an active filter. (Say using a buffer such as the BUF04 from Analog Devices).

The filter reduces any LO leakage, and also limits the noise bandwidth to about 1 MHz.

4.7 Selectable Filters

Perhaps four choices :

- Wideband
- CFL455AG2 (6 dB BW +/- 19 kHz) - Murata ceramic
- CFM455E (6 dB BW +/- 8 kHz) - Murata ceramic
- CFM455I (6 dB BW +/- 2 kHz) - Murata ceramic

I suggest a GaAs switch - eg, Hillite 182514.

4.8 Step Attenuator

If the input noise to the 'Backend' system is very wide, some extra gain may be required after the narrow bandwidth filters. Perhaps if a GaAs step attenuator is used at the input, it could be used here as well, to give the required overall gain after the ceramic filters.

4.9 455 kHz amplifier

see above.

4.10 Second Mixer

Something from Mini-Circuits would be suitable. Perhaps a higher level one, so the signal level may be a little higher, and have less gain after this mixer. Perhaps a TUF-3MH model.

4.11 45 kHz Amplifier

Same comments as for the 455 kHz amplifiers.

4.12 Low Pass Filter

To reduce LO leakage and reduce any out-of-band noise, a corner frequency of (say) 100 kHz. Again, an L-C filter or an active filter.

4.13 Amplifier, IF(out) Power Detector, IF(out) Monitor

Similar comments about the amplifier.

The IF Power Detector can again be a back diode.

The IF Monitor should be run to the front panel.

4.14 First-LO Power Divider

A standard in-phase power divider - some Mini-Circuit unit, followed by two amplifiers, one for each conversion chain. The amplifiers will reduce any IF leakage back down the LO input. Q-Bit amplifiers QBH-102 (or QBH-115) could be used.

4.15 Second-LO and Power Divider

A LO frequency of (say) 0.5 MHz could be used, followed by a power divider and some amplifiers.

A reference of 10 MHz would normally be available. The LO could be derived from this.

5 Physical Construction

We need to accomodate the step attenuators thumb wheels switches. There are the IF monitor outputs.

If we buffer the detector outputs for the input and output IF of both target and reference antennas, these could be sent to the SR830 analog channels, to be downloaded to the computer.

The circuits could be built in our standard RF boxes, giving good isolation. This suggest a standard 19 inch rack enclosure, about 4 inches high.