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Walsh Switching -- Required accuracy and possible schemes

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The IF signals from each GMRT antenna will be modulated with a Walsh function to reduce the effect of coupling between the different channels. Demodulation of the Walsh function will be done after sampling in the correlator data preparation card. To recover original signal to noise ratio, it is necessary that the demodulating signal is synchronous with modulating function. However since the modulating and demodulating circuits are many kilometers apart, this synchronisation could be a problem. The purpose of this note is to specify the accuracy of the required synchronisation and suggest possible schemes for implementing the Walsh modulation.

The Walsh function is an orthogonal sequence of plus and minus ones. The highest sequency Walsh function is a square wave and we will discuss the question of the required accuracy of synchronisation for the case of a square wave since it is the simplest to visualise and has the most stringent requirement of synchronisation. If the period of the square wave is T, the modulating function is +1 for T/2 and -1 for T/2 and the avearge value of the modulated signal is 0 if the signal does not vary over the interval T, which we will assume is the case. The demodulating function is the same square wave and since the product of the two functions is identically equal to one, the demodulated signal is same as the original function and has an integrated value of ET over the period, where E is the amplitude of the signal. If the demodulating function is not exactly synchronised and is offset by an interval t, the demodulated signal is 1 only for a interval (T-2t) while it is -1 for a period of 2t. Thus the integrated value of the signal is now less being equal to (T-4t). The noise does not depend on the error in synchronisation and the signal to noise is reduced by (4t/T) %. Thus , if we are prepared to tolerate a 1% loss in the sensitivity due to imprecise synchronisation, the maximum synchronisation error that we can tolerate will be less than 0.0025T. The kind of switching frequencies required for GMRT imply T of the order of 10ms implying synchronisation to within 25 microsec.

The kind of signals being measured by radio astronomers is not deterministic. But the kind of arguments given above are still valid if consider the effect of poor synchronisation on the output of a two element interferometer, when the demodulation is done before correlation as is the case for GMRT. On each arm of the interferometer, the incoming signal, after Walsh modulation and demodulation, is multiplied either by +1 (most of the time) or -1 for a time 2t, where t is the synchronisation error. When the signal on both arms is multiplied by the same value (+1 or -1), the output of the correlator is the true output. When the signal on one of the arms is multiplied by -1, then the output of the correlator reverses sign and tends to cancel the required signal. To calculate the effect of synchronisation error on the signal to noise ratio, one has to know both the errors on each arms and also the correlation properties of the errors. The worst case situation is when the times when the errors occur have no ovelap in which case the loss of S/N for the interferometer will be twice as large as the case for a single channel ie the worst case loss of sensitivity will be given by (8t/T)%. Thus with T=10millisec, synchronisation to about 10 microsec accuracy should be enough for GMRT requirements.

In the GMRT electronics, the Walsh demodulation is done in the Central Electronics Buiding while the modulation is done at antenna front end which could be 15km away. If we generate the Walsh function in the CEB and send it to the antenna via the optical fibre, and bring the modulated IF back to the CEB for demodulation, because of the finite velocity of light, the modulated IF is delayed by $2x15/3.10^5$ = 100 microsec. If we want to use the originally generated Walsh function for demodulation also, this function has to be delayed by a value between 0 and 100 microsec (depending on the distance to the antenna) before using it for demodulation. Since the path length through the optical fibre is fixed, this delay is expected to be constant with time and once it has been estimated for each antenna by maximising the S/N on a strong source, this delay should be introduced by suitable elecronics before the Walsh function is given to the data preparation card in the correlator system which does the demodulation. (Note This delay is quite distinct from the variable delay that is required to maximise coherence.)

No provision has been made at present for sending the Walsh function on the optical fibre. To do Walsh modulation / demodulation without sending the function over the fibre, one needs to have two independent Walsh function generators, one at the antenna and one at the Central Electronics Building, both generating the same function. But now it becomes important to ensure that the synchronisation of the two Walsh functions. (Note The term synchronisation is used here loosely. What is required is not that the two Walsh functions start at the same absolute time but that time difference between the two Walsh functions when received at the Central Electronics Building, does not change by more than 10 microsec between two measeurements of the delay (which could be weeks or months apart)). This synchronisation could be done by sending periodic initialisation pulses to both the Walsh generators. A one pulse per second that is tied to the master clock in the Central Electronics Building could be sent on the optical fibre for this purpose. Such a pulse could be also useful for other purposes.

WALSH FUNCTION MODULATION

In order to simplify discussion, we assume below that the fastest period in the Walsh function sequency is 10 ms, so that the sequency consists of a bit which flips between two levels (+1 or -1) after some multiple of 10 ms. The slowest period is 128 x 10 ms =1.28 s, which defines the length of the sequency. The sequency repeats itself after every 1.28 s. Once initiated, the modulation should persist for at least a half-hour period. In the following paragraphs, we summarise the implications and possible schemes as guidelines to the engineers to define a suitable strategy.

START/END OF MODULATION

The start of demodulation at the CEB should be within 10 us of the beginning of modulation on the received signal from the remote stations, in order to ensure adequate synchronisation. Thus there should be a mechanism to synchronise the clocks at central and remote stations to such an accuracy whenever it is required to turn on Walsh modulation. This is simply provided if, e.g., a 1-sec pulse from rubidium standard is broadcast to all stations, and recovered at eachstation. The propagation delays between the CEB and the individual stations will be constant, which can be calibrated along with the baseline parameters during the initial calibration runs with the array. (With the availability of such a pulse at a station, one can easily maintain absolute times at all stations by broadcasting the time - through computers - corresponding to the next pulse.) If we want to use the monitor/control circuitry for this purpose,we cannot attain the 10 us accuracy, rather will be limited to 64 us corresponding to 16 kbps.

SYNCHRONISATION OF MODULATION/DEMODULATION CLOCKS

If the modulation/demodulation clocks are independent, the irrelative drifts should not accumulate to 10 us over 1800 sec, which implies that the two clocks should be equal to an accuracy of one part in 180 million (0.006 ppm). The exception is when the clocksare resynchronised at faster intervals. For instance, if the two clocks are resynchronised at the beginning of each sequency,i.e., at intervals of 1.28 s, then the clocks need only be accurate to about 1 ppm. Since the modulation is done at the antenna feeds and demodulation is done within the correlator system at the CEB, the minimum requirement amounts to deriving the clocks used for Walsh modulation at stations from the rubidium standard at the CEB. One possibility using this scheme could be the following. The one-second pulse from the master station is used to start a counter to generate an offset for the beginning of the next Walsh sequency.The station computer will need to load the required offset so that one generates pulses at times 0, 1.28 s, 2.56 s, ... 1.28k which signify the beginning of each sequency. In such a scheme, it is possible to define station offsets such that the demodulation at CEB can begin simultaneously for all channels.

Requirements: Pattern generation at CEB and ALSO at each station;
One-second pulse from Rubidium clock received at all stations;
Delay-generation with necessary offsets for resetting pattern-generator counter for every sequency - at all stations.

The pattern generation effectively consists of a counter ticking at 10 ms intervals to output the address of a 256 word ROM, whose contents will give the desired combination of bits for the specific timeslice.The counter is reset externally as above at the beginning of each sequency. The counter and ROM can be located at the feed, but the two control pulses (reset and increment) will need to be carried from the antenna base to the top.

CENTRAL GENERATION AND DISTRIBUTION OF WALSH FUNCTIONS

It is possible to avoid redundant generation of Walsh functions at each station by transmitting them from the CEB. This eliminates the need for maintaining separate clocks for modulation/demodulation, but a synchronous link between CEB and the stations is still required. The scheme will roughly consist of the following stages:

(a) Generation of Walsh function pattern (2 bits / station, i.e., 60 bits each 10 ms);
(b) Transmission of the bits to the stations through the control/ monitor link;
(c) Generation of delayed pulses appropriate to the respective propagation delays for each station.
(d) transmitting of the delayed bits as necessary to the Data Preparation Card (DPC) of the correlator.

If the Walsh functions are generated centrally, we need to transmit 2 bits per station, i.e., total of 60 bits during every 10 ms. In addition to the Walsh modulation, we may also include a bit to indicate noise-calibration to be turned on/off. In order to cater for this, we need provision for 3 bits to be communicated to every station, i.e., total of 90 bits to be transmitted every 10 ms. The net data rate is 9 kbits/s, plus packet overheads.This essentially amounts to time-multiplexing the patterns to stations; each station will accept a unique group of 3 bits from among the 90 bits.