# INVESTIGATION OF DIGITAL TV -TERRESTRIAL SIGNAL FOR RADAR APPLICATION

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**Abstract- Over the past years, there has been much interest shown in bistatic radar using existing non-cooperative transmitters. Previous studies within this area have first of all investigated analogue television based bistatic radar. It was concluded that this type of radar is best suited for Doppler rather than range measurement. Currently, analogue television is being replaced by digital video broadcasting – terrestrial standards, hence the need to investigate the possibility of using a Digital television–terrestrial (DTV-T) signal for radar applications. This paper represents the first step in analysing a DTV-T signal ambiguity function. Theoretical and computer analysis show that the ambiguity function, in addition to its thumbtack shape, contains some deterministic peaks. A method to filter out these unwanted peaks is also outlined.**

## INTRODUCTION

Analogue TV based bistatic radar was studied in [1][2][3]. Analysis in Griffith [1][2] showed some specific ambiguity function if TV sync pulses are used and illustrated that this type of radar is best suited for Doppler rather than range measurement. The main shortcoming of the system was its ambiguity surface, having only 9600m of unambiguous range. Howland [3] showed how the carrier of the television broadcast can be used to detect and track targets. The limitation of using only the carrier is that there will be no range resolution. Nevertheless these systems have some attractive features.

A new form of modulation – COFDM (coded orthogonal frequency division multiplex) is used to transmit the video signal of approximately 7.61MHz bandwidth. This technique involves modulating the data on to a large number of carriers using FDM. A similar type of technique, using OFDM modulation was reported by Levanon [4] for generating signal for radar application. There are two differences in the approach adopted in this paper as compared with Levanon. First, an existing transmitter (DTV-T) is used, rather than designing one. Second, the signal generated by the DTV-T transmitters may not be optimum for radar application and some extra signal processing may be required at the receiver.

This paper investigates the characteristics of the transmitted Digital television (terrestrial) DTV-T waveform on the basis of its ambiguity function and describes the optimum (or sub-optimum) signal processing required to achieve the desirable characteristics of the waveform for radar application. Calculations show that 10 KW TV transmitters have enough potential for typical aircraft detection over 100 Km and more [5].

## THE DTV-T TRANSMISSION SYSTEM

Fig 1 depicts the system in functional block of equipments, which performs the adaptation of the TV baseband signal from the output of the MPEG-2 multiplexer to the terrestrial channel characteristics. The processing applied to the output transport stream of MPEG-2 multiplexer, can be divided into two major categories. Firstly, applying the forward error correction (FEC) or error coding. Secondly, using the Orthogonal Frequency Division Multiplexing (OFDM) modulation method on the coded data for transmitting it over the airwaves. The combined processing is abbreviated as COFDM, where 'C' represents the error coding. COFDM involves modulating the error coded serial bitstream data over many closely spaced individual carriers (orthogonal carriers), using the frequency division multiplexing (FDM) technique. COFDM can be implemented very efficiently by using the inverse discrete Fourier transform (IFDT), which is an equivalent of FDM. Therefore a COFDM signal is made up of discrete number of carrier frequencies transmitted altogether for a particular length of time, $T_u$. These carriers are spaced in such a way that they occupy the 7.61 MHz bandwidth, allocated to the DTV-T signal. In addition to the data the carrier carries the transport parameter signals (TPS) and pilot signals, which are used for transmission parameters and channel estimation purposes. Another important term in a COFDM signal is the guard interval. It is a small segment added at the beginning of the signal. This segment is identical to the segment of same length at the end of the signal. This is now called COFDM symbol, of duration $T_s$, see fig 2. A COFDM Frame is made up of 68 COFDM symbols, with 4 frames making up one COFDM super frame. The actual equation used for DVB-T COFDM transmission is given by the following equation [6]:

$$Y(t) = \mathrm{Re}\left\{ \exp\left( j(w_o t + \phi) \sum_{m=0}^{+\infty} \sum_{l=0}^{67} \sum_{k=k_{\min}}^{k_{\max}} C_{m,l,k}.\psi_{m,l,k}(t) \right) \right\}$$

Where

$$\psi_{m,l,k}(t) = \left\{ \begin{matrix} \exp\left( j2\pi \frac{k'}{T_u} (t - \Delta - l.T_s - 68.m.T_s) \right) & (l + 68.m).T_s \le t \le (l + 68.m + 1).T_s \\ 0 \quad \text{else} & \end{matrix} \right\} \qquad \text{……….} \quad (1)$$

m: frame number
k: denotes the carrier number
*l*: denotes the COFDM symbol number
k: is the number of transmitted carriers
$T_s$: is the symbol duration
$T_u$: is the inverse of the carrier spacing
Δ: is the duration of guard interval
$\omega_o$ : is the centre frequency of the RF signal (radians)

$k'$: is the carrier index relative to the center frequency, $k' = k - (K_{max} + K_{min})/2$

$C_{m,0,k}$ : complex symbol for carrier k of the data symbol no. 1 in frame m

$C_{m,l,k}$ : complex symbol for carrier k of data symbol no. $l$+1 in frame m

$C_{m,67,k}$ : complex symbol for carrier k of the data symbol no. 68 in frame m.

The summation from $l$=0 to 67 in equation (1) defines the COFDM frame, $k = k_{min}$ to $k_{max}$ defines the active number of carriers in the COFDM symbol. Fig (3) shows the DTV signal in time and frequency domain.

## THEORECTICAL DESCRIPTION OF AMBIGUITY FUNCTION OF THE DTV-T

The ambiguity function largely depends upon the characteristics of the transmitted waveform. Therefore to predict the shape of the ambiguity function in time and frequency domain, it is necessary to analyse the detail characteristics of the transmitted signal in terms of modulation, bandwidth, randomness and possible correlation within the signal. This section deals with the theoretical investigation of randomness and correlation within the transmitted DVB-T signal.

It is clear from fig 1that the transmitted signal will have two components: Random and deterministic. The random component is the result of MPEG-2 compression algorithm as it removes as much possible similarities between the images [7].This followed by the channel coding (energy dispersal, interleaving) removes the remaining correlation within the signal. The deterministic component is due to the guard interval and pilot signals added to the transmitted DVB-T signal (explained in the next section). Therefore it is predicted that the ambiguity function will have a thumbtack shape due to random component and some peaks in the time domain due to the deterministic component. No deterministic peaks will be generated in the frequency domain as we are considering a continuous wave signal.

## PROOF OF CAUSE OF DETERMINISTIC PEAKS

**Guard Interval:**

The most clearly seen repetition in the DVB-T signal is due to the guard interval. As seen from fig 2 a guard interval is a copy of the last part of the COFDM symbol. This correlation within the signal will produce a deterministic peak in ambiguity function at a time interval of useful symbol duration of $T_u$ .

**Pilot Signals:**

The second cause of repetition within the signal is due to the pilot added in the transmitted DVB-T channel. These signals occupy specific carrier positions in a COFDM symbol as described according to European DVB-T specifications [6]. The pilot signals are BPSK modulated where the reference information bits are derived from 11- stage PRBS (Pseudo Random Binary Sequence), which is a series of values, one for each of the transmitted pilot carriers. It is found that when the different BPSK modulated pilot carriers are added together (IFFT), they tend to produce a signal similar to amplitude modulation, with a repetitive envelope. To prove, this repetition due to pilot signals, the two different types of pilot signals in DTV waveform are considered separately.

*Scattered Pilot Signal Transmitted only:*

According to the DVB-T specifications, the scattered pilots in each symbol are placed at a carrier difference interval of 12 in frequency direction. The positions of the scattered pilot signals are repeated after every 4 symbols duration. To check the repetition in signal, when only scattered pilot signals are transmitted, the following equation is considered which represents the carrier positions of the scattered pilot signals in the first symbol

$$Y(t) = 1 + \cos(2\pi \frac{12}{T_u} t + p) + \cos(2\pi \frac{24}{T_u} t + p) + \cos(2\pi \frac{36}{T_u} t + p) + \cos(2\pi \frac{48}{T_u} t + p) + \ldots\ldots \qquad \ldots\ldots\ldots (2)$$

Where p takes the value 0 or $\pi$ depending upon the reference sequence from the PRBS. If the DC component is neglected for a moment, it is found that the rest of the waveform has a fundamental frequency of $12/T_u$ . Hence its ambiguity function will generate peaks at a time interval of $T_u/12$ and $4T_s$ (as the frequency positions of equation (2) are again repeated after four symbols).

*Continuous pilot signal transmitted only:*

In this case it assumed that only continuous pilot signals are transmitted and the data at rest of the carrier positions are zero. It is found from the DVB-T specifications that the carrier indexes for continuous pilot signals are harmonic of the fundamental frequency, $3/T_u$ within the symbol duration and their carrier positions do not change from symbol to symbol. This clear from the following equation that represents the carrier indexes within the symbol:

$$Y(t) = 1 + \cos(2\pi \frac{48}{T_u} t + p) + \cos(2\pi \frac{54}{T_u} t + p) + \cos(2\pi \frac{87}{T_u} t + p) + \cos(2\pi \frac{141}{T_u} t + p) + \ldots\ldots \qquad \ldots\ldots\ldots (3)$$

Where p takes the value 0 or $\pi$ depending upon the reference sequence from the PRBS. Therefore if only continuous pilot signals are transmitted, the ambiguity function will have a repetition at an time and interval of $T_u/3$ and $T_s$.

*TPS signals transmitted only*:

The TPS signals occupy random frequency position within the symbol, but their position are repeated from symbol to symbol, therefore no inter symbol peaks will be generated, however intra symbol peaks will occur at an interval of $T_s$.

It is concluded that when all the pilot and TPS signal are sent together, they produce a repetitive envelop of duration $T_u/3$, $T_u/12$, $T_s$ and $4T_s$.

## PROPOSED METHOD OF DETERMINISTIC SIGNAL MITIGATION AT THE RECEPTION SIDE

It is clear from the above discussion that the repetition within the DVB-T signal produce unwanted deterministic peaks in the ambiguity function. The presence of these peaks deteriorates the quality of DVB-T signal for radar application. Therefore some method is required to eliminate the repetition within the transmitted signal. The proposed system consist of receiving on two channels – one to receive the direct DVB-T signal, called the heterodyne channel, and the other to receive the reflected signal from the target called the radar channel. To eliminate the repetitive portion of the transmitted signal, it is proposed that the some sort of signal processing must be applied to the signal received from the heterodyne channel before it is coherently integrated with the reflected signal, see fig 4. As mentioned previously the repetition is due to the guard interval and the pilot signals. The guard interval is a copy of the last part of the COFDM symbol there is a correlation between two parts of a symbol. A signal can therefore be produced that identifies the position of the symbol and filters out the guard interval. The pilot signals are scattered in time and frequency domain of the transmitted signal. As the transmitted signal is continuous in time, these pilot signals cannot be removed in time domain, but can be eliminated in frequency domain as they occupy specify frequency positions. Fig 5 shows the detail functional block diagram of the processing in the heterodyne channel before correlating it with the signal received from radar channel. The time synchronisation block finds the optimum timing for the start of the FFT window The TPS decoder helps in detecting the start of COFDM frame, which initialises the process of removing the pilot signal from the DVB-T signal.

## AMBIGUITY ANALYSIS VIA COMPUTER SIMULATION

To confirm the theoretical analysis of the ambiguity function done in previous sections, a computer simulation model was developed. This model generates DVB-T signal according to European specifications [6] and also computes the ambiguity function of the DTV-T signal. The symbol duration $T_u$ was taken as 224μs and guard interval of 7μs duration, making the total symbol duration $T_s$ of 231μs. In spite of the fact that the ambiguity function is a normalised value, for this research there is a reason to operate within some range of signal /target parameters. This will not decrease the generality, but will increase the viability of the discussing parameters. Therefore, it is assumed that the TV station operates at central frequency of $f_c$ = 500 MHz and a bandwidth of approx.7.61 MHz. The maximum radial velocity of the target is approximated equal to $V_r = 1000$ m/sec (corresponding to Doppler shift of approx 3KHz). As it was mentioned above that a 10 Kw transmitter at this frequency within some general assumptions provides typical target detection over 100 Km. In terms of delay, 1ms (corresponding to 150 km) will be the typical number for this analysis. Another important factor that should be taken into account is the coherent integration interval, as the real target cannot be viewed as point target. Here for demonstration purposes we have assumed the coherent integration interval also of about 1msec, as in reality it can be much larger than that, about 0.5 sec for an average size aircraft [8].

Fig 6 shows the ambiguity function (AF) of the DTV-T signal with zero Doppler shifts. It clearly agrees with the theoretical prediction, as it has some deterministic peaks at the correct time interval due to guard interval and pilot signals (discussed in the next section). The guard interval peak is not visible, because of its very low power (approx 3%) as compared with the main peak and due to the high sidelobe levels. The deterministic peaks become more clearly visible, with increase in coherent integration interval as the root mean square level (RMS) of random sidelobe level reduce by factor of $\sim 1/\sqrt{N}$ ., where N is the number of coherent integrations see fig (7)(8).Fig 9 –11 shows the AF of the DVB-T signal when only scattered, continual and TPS signals are being transmitted. Fig 9 is the case of only scattered pilot signal, it agrees with the theoretical analysis as inter and intra symbol repetition occurs at an interval of $T_i \sim$ Tu/12 (1.867E-5 sec) and $T_I = 4T_s$ (9.24E-4 sec). Similarly Fig 10 shows the repetition of $T_i \sim T_u/3$ (7.467E-5 sec) and $T_I$ = Ts (231E-6 sec) due to only continual pilot signal. Fig 11 shows only intra symbol repetition of $T_I = T_s$ due to only TPS signals, due to their random frequency location in COFDM symbol. As predicted before, when all the pilot and TPS signal are transmitted, the resulting AF will have repetition at an interval of $T_u/12$, $T_u/3$, $T_s$ and $4T_s$ shown in Fig 12. Fig 13 shows unambiguous AF (with zero Doppler) with the removed guard interval & pilot signals.

AF with zero delay is shown in fig 14. As expected it has Sinc(x) shape (due to rectangular envelop of the processed signal). From Fig 14-15 a range and velocity resolution (taken between –4 dB point) of 9 meters and 135 m/sec respectively. It should be noted that a much higher Doppler resolution could be obtained by increasing the coherent integration interval. Finally fig (16) represents the 3D view of ambiguity function in time and frequency domain.

## CONCLUSION

The results of the analysis presented here can be summarised as follows; The DTV signal ambiguity function is not an ideal thumbtack shape. It has got some peaks due to guard interval and pilot signals in the transmitted signal. It was shown that these peaks couldn't be reduced during coherent integration; whereas RMS value of random sidelobes is reduce by factor of $\sim 1/\sqrt{N}$ . A method of filtering out these peaks was proposed and implemented. A range resolution of approx. 9 meters was obtained. The problems associated with this type of radar are: a) The high sidelobe level of the autocorrelation function b) Separation of direct and reflected signal and c) Ground clutter. All these factors contribute to the complexity of the receiver. Our future work will focus on reducing the complexity of the receiver and methods of reducing the computational load on the receiver

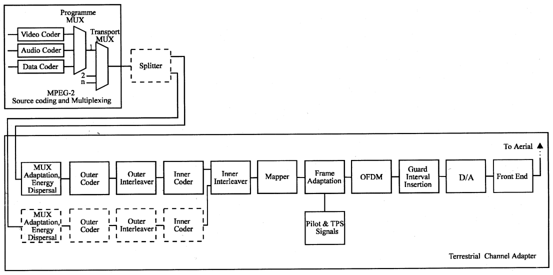


**Fig 1: Functional block Diagram of DVB-T (source ETS[6])**

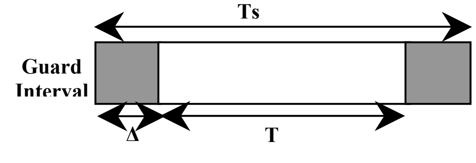


**Fig 2: The COFDM symbol**

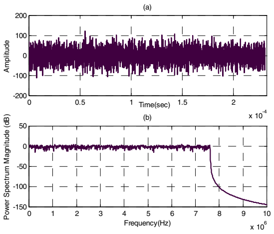


Fig 3: DTV-T signal (a) Time domain (b) Spectrum

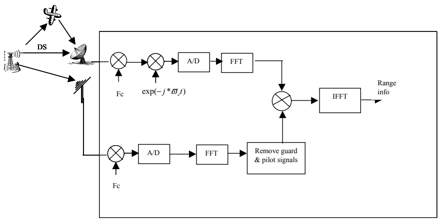


Fig 4: Receiver Structure

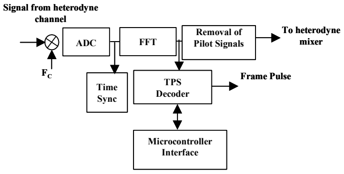
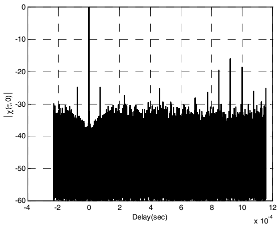
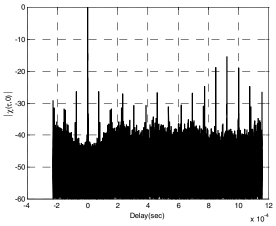
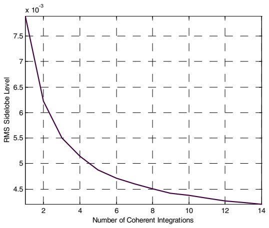


Fig 5: Functional block diagram of the process involved in removing Guard interval & pilot signals





Fig(6) AF of DTV-T signal with zero Doppler Shift . Fig(7) AF of DTV-T signal with Coherent Integartion



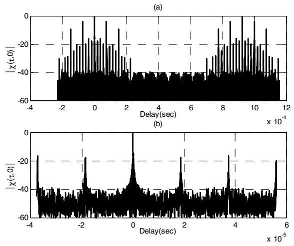
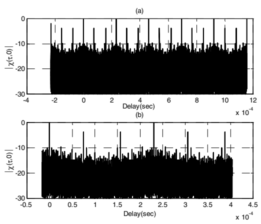


Fig 8 RMS value versus number of integration Fig 9 (a) AF with only scattered signal transmitted (b) zoomed view



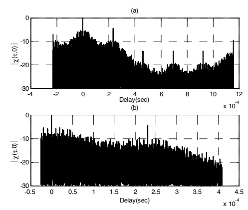


Fig 10 (a) AF with only continual signal (b) Zoomed version Fig11 (a) AF with only TPS signal (b) Zoomed view

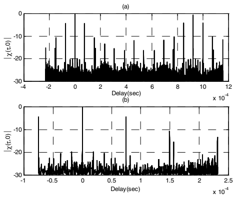
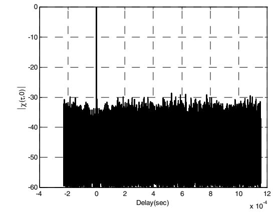


Fig 12: (a) AF with all the pilot signals transmitted (no data) (b) Zoomed view



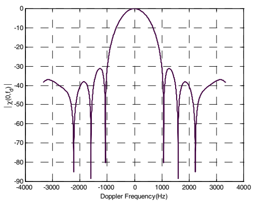
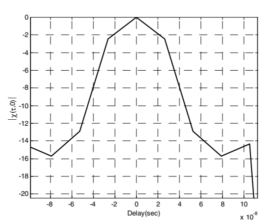


Fig 13 : AF after the removal of guard interval and pilot signals. Fig 14: AF with zero delay (frequency domain).



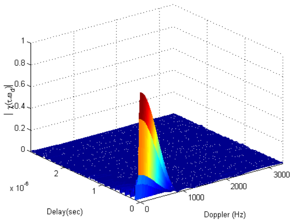


Fig 15 : Zoomed main peak of the AF (zero Doppler). Fig 16 3D view of the thumbtack ambiguity function (linear scale).

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