Performance of an Echo Canceller and Channel Estimator for On-Channel Repeaters in DVB-T/H Networks

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***Abstract*—This paper investigates the design and performance of an FIR echo canceller for on-channel repeaters in DVB-T/H network within the framework of the PLUTO project. The possible approaches for echo cancellation are briefly reviewed and the main guidelines for the design of such systems are presented. The main system parameters are discussed. The performance of an FIR echo canceller based on an open loop feedforward approach for channel estimation is tested for different radio channel conditions and for different number of taps of the FIR filter. It is shown that a minimum number of taps is recommended to achieve a certain mean rejection ratio or isolation depending on the type of channel. The expected degradation in performance due to the use of fixed point rather than floating point arithmetic in hardware implementation is presented for different number of bits. Channel estimation based on training sequences is investigated. The performance of Maximum Length Sequences and Constant Amplitude Zero Autocorrelation (CAZAC) Sequences is compared for different channels. Recommendations are given for training sequence type, length and level for DVB-T/H on-channel repeater deployment.**

***Index Terms*—CAZAC, channel estimation, DVB-T/H, echo cancellation, MLS, on-channel repeaters, SFN, training sequences.**

I. Introduction

The increasing spread of Digital Video Broadcasting services either terrestrial (DVB-T) or more recently handheld (DVB-H) require efficient and economic network technologies for successful delivery. DVB-T and DVB-H [1]–[4] are key radio broadcast network technologies which are expected to complement emerging technologies such as WiMAX and its derivatives in future 4G hybrid networks. These technologies use Orthogonal Frequency Division Multiplexing (OFDM), which is a technique that distributes data over a large number of carriers spaced apart at precise frequencies providing frequency diversity.

Single Frequency Networks (SFN) can be considered as an effective and economical approach for DVB-T/H coverage. SFN advantages include better coverage, less interference, less power, and higher reliability. SFNs can also free up extra TV channels, resulting in more efficient use of the spectrum [19]. The main purpose of an on-channel repeater [5], [6], [20] is to extend the coverage of the DVB-T/H network in areas where services are inaccessible. The on-channel repeater receives DVB-T/H signal off air, amplifies it and then retransmits it on the same frequency as received. In this way, the repeater system will improve reception in areas of poor coverage as in sparsely populated areas, indoors and obstructed mobile reception thus extending DVB-T/H coverage or achieving hole filling purposes.

There is a need for high isolation between transmit and receive antennas to minimize coupling and to keep the system stable. Physical separation of the antennas is necessary but usually not sufficient to reduce the impact of unwanted echoes or feedback channel. Digital signal processing (DSP) techniques are necessary to reduce the unwanted echoes in the feedback path between antennas, which is also known as coupling loop interference, and thereby improve the isolation figure.

This paper investigates several aspects related to the design and performance of an echo canceller for low cost on-channel repeaters within the framework of the European Commission IST project: PLUTO [7]. The Physical Layer DVB Transmission Optimization project: PLUTO, researches novel techniques for broadcast transmitter networks that will optimize the use of spectrum and minimize the performance demands on end user equipment.

The paper is organized as follows: Section II summarizes the main network parameters of DVB-T/H and highlights some of the differences among systems deployed in Europe. Section III introduces the need for echo cancellation and discusses the main possible approaches and design parameters of an echo canceller for on-channel repeaters. The block diagram of the proposed repeater is then presented. Section IV investigates the performance of the echo canceller under different radio channel conditions and for different number of taps for the transversal filter as well as the expected degradation in performance due to the use of fixed point arithmetic. Section V, investigates channel estimation based on training sequences and presents performance figures for different training sequence lengths and types. Finally, Section VI summarizes the main conclusions.

II. Main Network Parameters for DVB-T/H

The main four transmission parameters for the DVB-T/H are the FFT size, the guard interval, the modulation and the coding rate. There are three main modes for the DVB-T/H standards

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TABLE I
SOME KEY PARAMETERS OF THE DVBT/H SIGNAL FOR AN 8 MHz CHANNEL

Parameter	2K mode				4K mode				8K mode			
Number of active carriers K	1705				3409				6817			
FFT size	2048				4096				8192			
Elementary Period T (μs)	7/64				7/64				7/64			
Useful Symbol Part Tu (μs)	224 μs (2048 T)				448 μs (4096 T)				896 μs (8192 T)			
Carrier Spacing 1/Tu (kHz)	4.464				2.232				1.116			
Guard Interval	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard Interval Duration (μs)	56	28	14	7	112	56	28	14	224	112	56	28

based on the FFT size. These modes offer a tradeoff between mobility reception and SFN cell coverage as follows [1]–[4]:

- 2K mode: allows extremely high speed reception (e.g. highways and trains) but small cell radius coverage up to around 16 km for the 1/4 guard interval. This mode is currently used for UK DVB-T networks. The small cell radius makes the deployment of a low cost on-channel repeater to extend network coverage for this mode an important issue.
- 4K mode: is specifically introduced for DVB-H to work for most scenarios and allows very high speed reception (streets and highways) together with medium cell radiuses up to around 33 km.
- 8K mode: allows coverage radiuses of up to around 67 km with a 1/4 guard interval but is not very suited to high speed reception. The 8 K mode is used for almost all European DVB-T networks.

The above coverage values are for transmitters in with the same power and transmission timing.

Some of the parameters for a DVB-T/H OFDM signal are summarized in Table I [1]–[4]. The modulation and coding rate parameters determine the minimum required Carrier to Noise Ratio (CNR) for successful reception and together with the guard interval, a certain channel capacity.

The choice of a specific guard interval is a trade-off between capacity and SFN coverage. The guard-interval determines the maximum allowable delay between strong signals received from two transmitters in a single frequency network or from two strong echoes of the same signal. Signals whose relative delay is less than the guard-interval add constructively: signals whose relative delay exceeds the guard-interval interact destructively. However, because the guard-interval is achieved by allowing overlap between successive COFDM symbols, increasing the guard-interval reduces the overall data-capacity of the system. The longer the guard interval, the greater the allowable spacing between transmitters which reduces the number of transmitters to coverage a certain area at the cost of a loss of data capacity which can be used to increase the payload allowing more programs or alternatively increasing the ruggedness of the system by adding extra error protection data [17].

The UK is a specific situation in Europe because of the use of the 2K mode with (16 QAM, rate 3/4) or (64 QAM, rate 2/3). Examples of existing DVB-T specifications in the rest of Europe [8] include the German system (8 K, 16 QAM, rate 2/3) and the French and Scandinavian systems (8 K, 64 QAM, rate 2/3).

III. ECHO CANCELLER DESIGN FOR DVB-T/H ON-CHANNEL REPEATERS

The basic on-channel repeater is an amplifier. The general requirements of such systems are usually a high gain above 80 dB, large dynamic range and good selectivity as well as good isolation between the transmitter and receiver antennas. The main focus of this on-channel repeater design is to improve the isolation.

The main problem with on-channel repeaters is the effect of strong feedback signals from the transmitting antenna towards the receiving antenna.

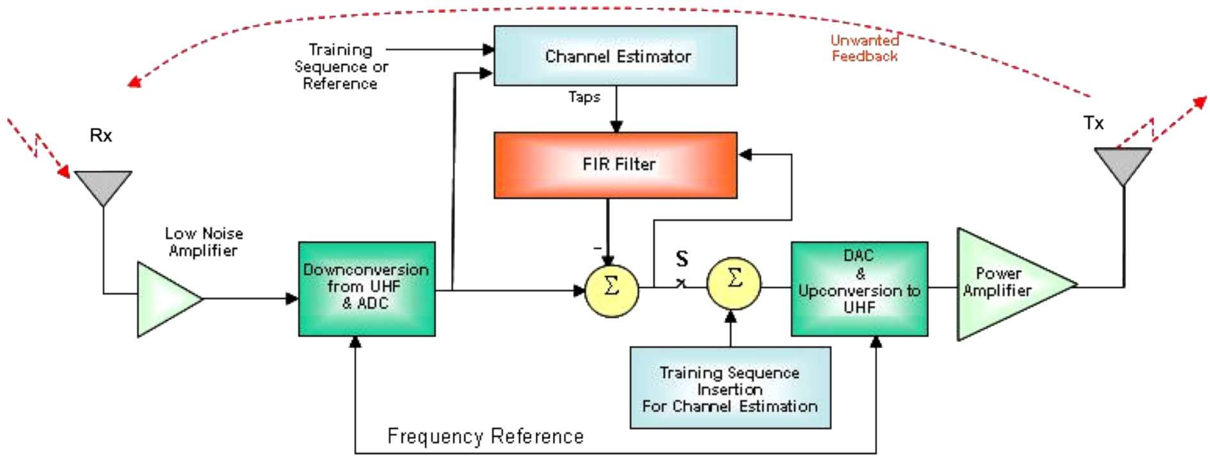
These feedback signals can interfere with the weak received signal of the repeater causing oscillations and system instability. This unwanted feedback signal is also known as coupling loop interference and arises when the gain of the amplifier is larger than the isolation between the antennas at the two ends of the repeater as well as from echoes or reflections from the surrounding environment.

A first solution to the coupling loop interference problem is to increase the physical separation distance between the transmitter and the receiver antennas of the on-channel repeater. This is necessary but generally not a sufficient solution for the reduction of unwanted feedback.

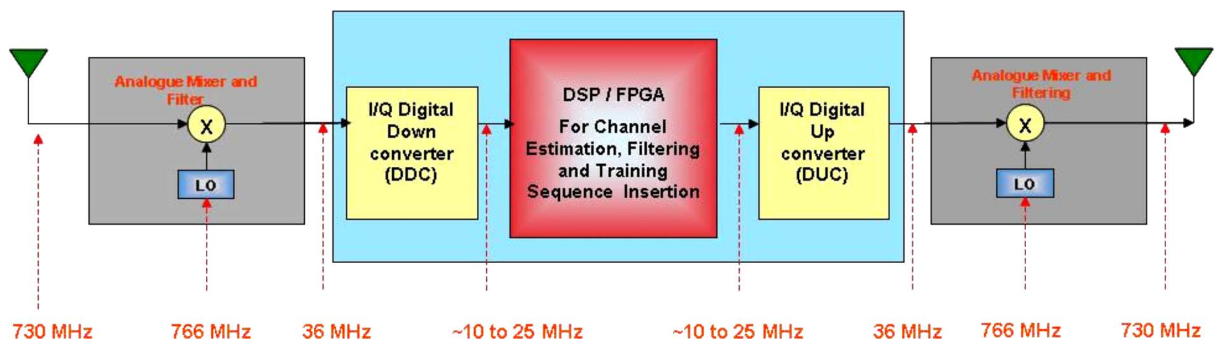
Effective cancellation can be obtained by combining the physical separation of the antennas together with digital signal processing (DSP) techniques to model and remove the feedback channel between the antennas. To do this, the main requirement is an effective technique for the unwanted feedback channel (echoes) estimation.

The possible approaches for echo cancellation using DSP techniques fall in two main categories:

1) Time Domain Signal Processing
   This can be implemented by using time domain filter with complex coefficients to model and reject unwanted echoes. There are many design tradeoffs. These include the selection of the filter type (FIR or IIR), the selection of a suitable channel estimation and weight updating algorithms



(a)



(b)

Fig. 1. (a) Block diagram of the proposed on-channel repeater with echo canceller. (b) Block diagram of the repeater system showing the main filtering stages with an example of a UHF channel at 730 MHz.

(feedback or feedforward) which will affect the stability and speed of convergence.

2) Space Domain Signal Processing
This category relies on adaptive antennas to place a null in the direction of unwanted echoes. This approach would require $\mathrm{N}+1$ antenna elements to reject N echoes and has the problem of the cost associated with RF components as well as the need of complex Direction of Arrival (DOA) estimation algorithms.

An example of time domain signal processing is the implementation of an echo canceller for DAB on-channel repeaters using a feedback approach based on the iterative Least Mean Square (LMS) algorithm [6].

A particular problem arises with implementing an echo canceling repeater suitable for the DVB-T parameters used in the UK. The short (7 μs) guard interval used, limits the time delay the repeater can introduce between the received and the reradiated signal.

Our proposed approach for a DVB-T/H echo canceller to be used within a low cost on-channel repeater is shown in Figs. 1(a) and (b). This approach relies on an open loop channel estimator. It is believed that this approach will both allow a low processing delay as well as an operation with comparatively poor isolation between receive and retransmission antennas.

A low power training sequence is buried in the transmitted OFDM signal for unwanted channel estimation based on the correlation principal. At startup, only the training sequence is fed to the transmitting antenna for initial channel estimation. This is accomplished using a switch S. This approach is selected since the training sequence is uncorrelated with the transmitted DVB-T/H OFDM signal and hence ensures good estimation. The update rate of the channel estimator should match the rate of change of the channel. This is discussed in more details in Section V. The drawback of this approach is that the training sequence will act as an unwanted interference and would slightly degrade the OFDM signal. The training sequence level should hence be as low as possible.

Once the channel complex coefficients are estimated, the taps of a Finite Impulse Response (FIR) filter are updated and the output of the filter is subtracted from the input ideally canceling the unwanted echoes and ensuring the stability of the on-channel repeater, which is the main purpose of the echo canceller.

The presented on-channel repeater architecture results in a universal design that can be used for any DVB or DAB standard since it does not rely on standard specific information like scattered pilots to estimate the unwanted channel.

The main echo canceller design issues are the maximum allowable processing delay, the sampling frequency used for DSP implementation, the number of filter taps and how it affects the performance, the impact of finite arithmetic (fixed point versus floating point implementation), the selection of a suitable training sequence for channel estimation and its

TABLE II
CHANNEL PROFILES AND DELAY SPREAD VALUES. (a) POWER DELAY PROFILE OF THE DIFFERENT CHANNELS; (b) DELAY SPREAD VALUES OF THE DIFFERENT CHANNELS

(a)

Rural Area RA6		Typical Urban TU12		Bad Urban BU12		Hilly Terrain HT12	
Relative Power in dB	Delay in ns	Relative Power in dB	Delay in ns	Relative Power in dB	Delay in ns	Relative Power in dB	Delay in ns
0	0	-4	0	-7	0	-10	0
-4	100	-3	200	-3	200	-8	200
-8	200	0	400	-1	400	-6	400
-12	300	-2	600	0	800	-4	600
-16	400	-3	800	-2	1600	0	800
-20	500	-5	1200	-6	2200	0	2000
		-7	1400	-7	3200	-4	2400
		-5	1800	-1	5000	-8	15000
		-6	2400	-2	6000	-9	15200
		-9	3000	-7	7200	-10	15800
		-11	3200	-10	8200	-12	17200
		-10	5000	-15	10000	-14	20000

(b)

Channel Type	Delay Spread in μs
Rural Area (RA6)	0.110
Typical Urban (TU12)	0.932
Bad Urban (BU12)	2.47
Hilly Terrain (HT12)	6.22

minimum possible level and the hardware platform used for implementation.

The maximum allowable processing delay of the echo canceller is selected to be below 30% of the guard interval duration. The 30% value is selected arbitrarily guided by the discussion in [6] for DAB repeater design to limit the delay to a fraction of the guard interval duration. This means that for 2 K mode with 7μs guard interval, the maximum allowable delay is around 2μs. This figure impacts the performance of the echo canceller because it sets a limit on the maximum number of taps used by the FIR filter. Another important parameter is the sampling frequency used for DSP implementation. The digital signal processing can in principal be carried out on real or complex signals. In the former case, a theoretical minimum Nyquist sampling rate of twice the signal bandwidth must be used. In the latter case, the minimum theoretical sampling rate is equal to the signal bandwidth. For an 8 MHz OFDM signal, the sampling rate chosen is either 20 MHz for real signals or 10 MHz if I/Q demodulation is selected for hardware implementation. Practical hardware implementation based on Xilinx Virtex 4 FPGA platform [18] reveals that if digital down and upconversions of more than 20 MHz is implemented for complex signal processing, the expected delay from the demodulation and digital conversion processes (including all analog external components for RF to IF conversions and bandpass filtering and excluding digital signal processing for the FIR filter) as shown in Fig. 1(b) does not exceed 400 ns. If 10 MHz processing is selected additional filtering stages are needed for digital down and up conversions which would increase the delay through the system to above 2 microseconds. On the other hand, for above 20 MHz I/Q processing more FIR filter taps are needed to achieve the same isolation figure compared to the case of 10 MHz processing as will be shown in the next section. The number of taps is a design tradeoff. A large number of taps increases the complexity of filter design and implies a larger hardware implementation and more processing power required by the hardware platform. The target is to limit the total delay of both analog and digital signal processing blocks.

The next section investigates the expected performance in terms of the Mean Rejection Ratio (MRR) or isolation improvement of the echo canceller under different channel conditions for different number of taps. The expected degradation in performance due to fixed point arithmetic will be also presented.

IV. ECHO CANCELLER PERFORMANCE UNDER DIFFERENT RADIO CHANNEL CONDITIONS

The COST 207 channel models [9] are used to investigate the performance of the echo canceller under different conditions. These are well established statistical models in the frequency range of interest (UHF) which has also been used for GSM and DAB tests.

They allow the evaluation of the echo cancellation algorithm for different profiles. The investigated profiles are: Rural Area with 6 paths (RA6), Typical Urban with 12 paths (TU12), Bad Urban with 12 paths (BU12) and Hilly Terrain with 12 paths (HT12). The power delay profile and delay spread parameters of the different channels are summarized in Table II.

Perfect channel knowledge is assumed and complex coefficients are used to replicate the channel profiles by the FIR filter taps. The target is to investigate the impact of number of

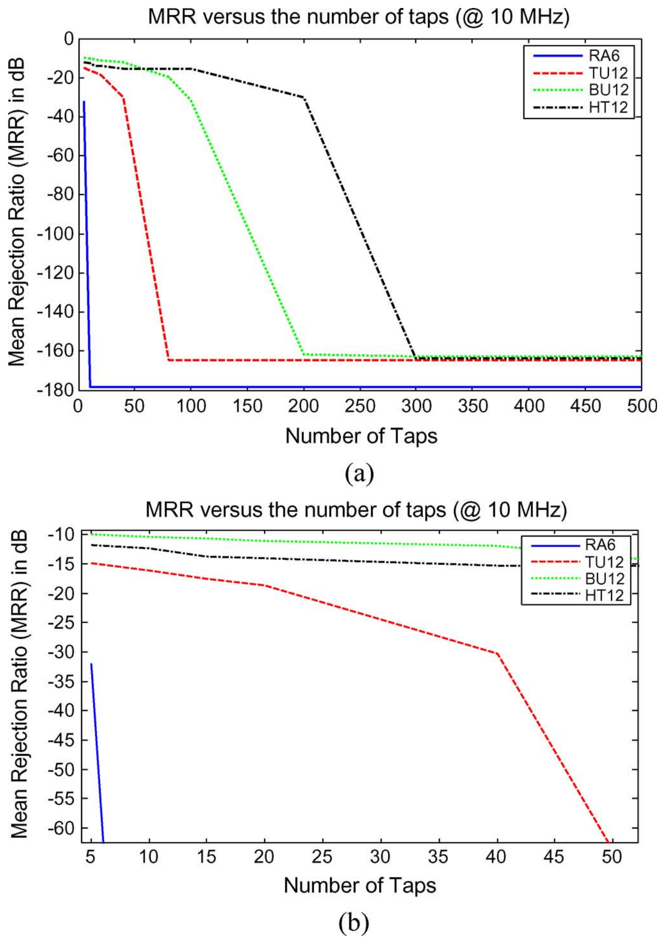


Fig. 2. (a) Expected isolation of the proposed echo canceller versus the number of taps at 10 MHz sampling and (b) zoomed version of a.

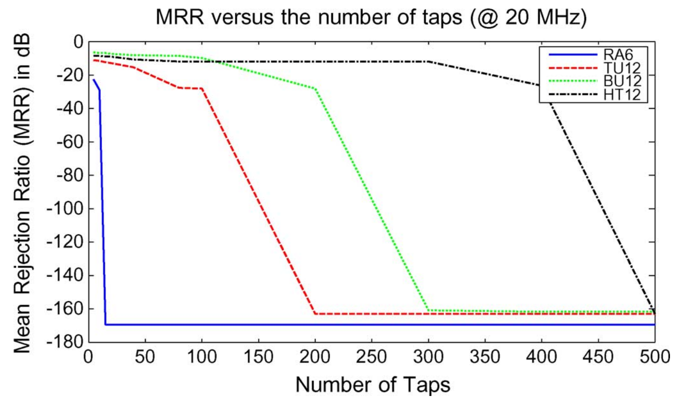


Fig. 3. Expected isolation of the proposed echo canceller versus the number of taps at 20 MHz sampling.

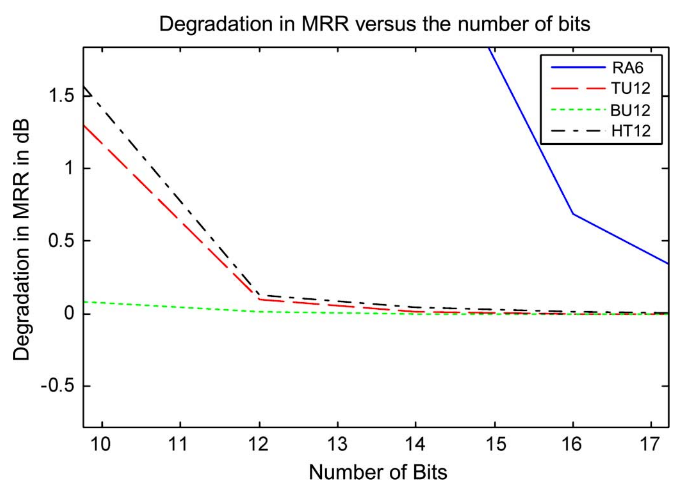


Fig. 4. Expected degradation in the isolation figure caused by the use of fixed point arithmetic.

taps on the isolation figure or the Mean Rejection Ratio (MRR) for 10 or 20 MHz sampling frequency (100 and 50 ns sampling time).

The Mean Rejection Ratio is defined as follows:

$$MRR = \frac{\sum_{n} |CIR_{Actual} - CIR_{FIR}|}{n},$$
$$MRR\,(\mathrm{dB}) = 10\log(MRR) \tag{1}$$

Where "$\mathrm{CIR}_{\mathrm{Actual}}$" is the actual channel impulse response, "$\mathrm{CIR}_{\mathrm{FIR}}$" is the truncated channel impulse response which is replicated by a fixed number of taps by the FIR filter of the echo canceller and "n" is the number of FFT points (taps) used to represent the channels.

It is expected that long or bad channel like BU12 or HT12 would require a large number of taps to achieve a certain isolation figure unlike short channels like RA6, which require only a few number of taps to replicate and cancel the channel. The performance of the echo canceller is shown in Figs. 2(a), (b), and 3 for 10 and 20 MHz sampling respectively.

For 2 μs processing time constraint, only 20 taps at 10 MHz or 40 taps at 20 MHz are available. It can be concluded from the above figures that except for "bad" channels like Hilly Terrain and Bad Urban, it is expected that the isolation achieved by the echo canceller will be above 20 dB for all channels.

For larger guard interval durations like in 8 K systems deployed in most of Europe, the maximum processing time would be around 8 μs. The isolation figure would improve dramatically because four times the number of taps (80 taps at 10 MHz sampling) can be now used for cancellation.

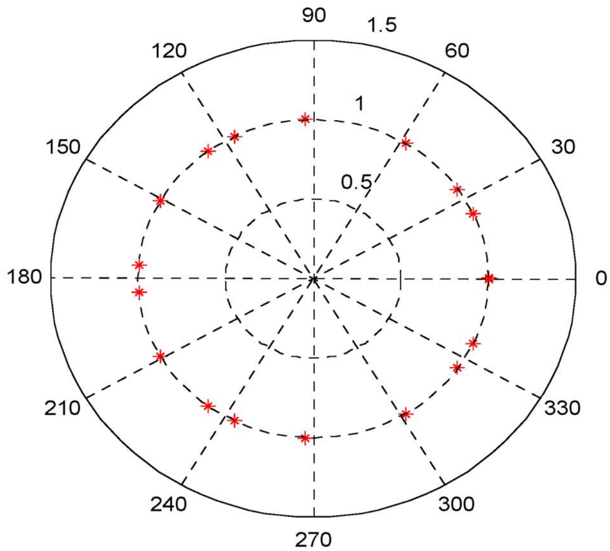
The degradation in the performance of the echo canceller (the achieved isolation) due to the use of fixed point arithmetic is simulated for different number of bits used for Analog to Digital Converter (ADC). The complex coefficients of the filter taps are forced to have discrete values or levels depending on the number of bits used rather than allowing floating point numbers.

The simulation results are shown in Fig. 4. It is concluded that if the number of bits used for ADC is 14 or above, the expected degradation in isolation will be less than 0.5 dB for almost all channels.

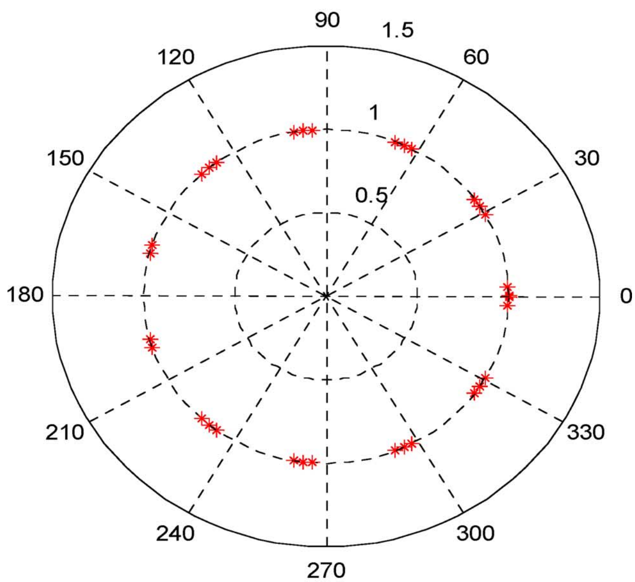
V. Channel Estimation

Channel estimation based on training sequences has long been used for measuring impulse responses [10], [11]. The basic idea is to send a known pseudorandom or pseudo-noise (PN) sequence to sound the channel transfer function based on the correlation principal.

For the purpose of the on-channel repeater, the training sequence should be uncorrelated with the DVB-T/H signal and its



(a)



(b)

Fig. 5. Roots of unity "R" for CAZAC sequences of length 256 and 900. (a) constellation of the 16 roots of unity for a CAZAC sequence of length 256; (b) constellation of the 30 roots of unity for a CAZAC sequence of length 900.

level should be as low as possible to reduce interference and be treated as additional noise. A complex scaled down version of the training sequence is added to the complex DVB (I/Q) signal before upconversion and amplification as shown in Fig. 1.

At startup and for initial channel estimation only the training sequence is sent. At the receiving end, the channel impulse response is estimated using the cross correlation of the received signal and the locally stored and known PN sequence. Denoting the transmitted PN sequence by p(t) and the channel to be estimated by h(t), then the received signal in the time domain r(t) can be expressed as:

$$\mathrm{r(t) = p(t) \otimes h(t)} \tag{2}$$

$(\otimes)$ denoting convolution and $\mathrm{p(t)} \in \{-1, 1\}$.

In the frequency domain, this can be written as:

$$\mathrm{R(w) = P(w)H(w)} \tag{3}$$

The channel impulse response can be then given by

$$\mathrm{H(w) = R(w)/P(w)} \tag{4}$$

Multiplying the numerator and denominator by the complex conjugate of P(w) then,

$$H(w) = \frac{R(w)P^*(w)}{|P(w)|^2} \tag{5}$$

The spectrum of the PN sequence in the frequency domain is approximately constant, hence the denominator can be considered as a constant.

The selection of a particular training sequence is a main design issue. Two categories with good correlation properties are investigated:

a) Maximum Length Sequences (MLS)
b) Constant Amplitude Zero Autocorrelation (CAZAC)

A. *Construction of MLS and CAZAC Sequences*

The lengths of the training sequences are selected to estimate channels extending to delays up to several microseconds and to have nearly ideal correlation properties (small or zero cross correlation).

For MLS, training sequences of lengths 511, 1023 and 2047 are selected. The generating polynomials for these sequences are [11]:

$$\mathrm{MLS(511) : x^9 + x^5 + 1} \tag{6}$$
$$\mathrm{MLS(1023) : x^{10} + x^7 + 1} \tag{7}$$
$$\mathrm{MLS(2047) : x^{11} + x^9 + 1} \tag{8}$$

Complex CAZAC sequences [12]–[16] have the advantage of ideal autocorrelation properties. They were historically used for radar accurate target tracking and synchronization in communication systems. These codes have zero autocorrelation except at zero delay.

To generate CAZAC sequences, the following procedure is implemented:

For a sequence of length z^2

- Select a number $\mathrm{z} > 1$
- The z different roots of unity $(1, \mathrm{R_1}, \mathrm{R_2}, \mathrm{R_{z-1}})$ are formed
- The z^2 sequence is formed through the following matrix M:

$$M = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & R_1 & R_1^2 & R_1^{z-1} \\ 1 & R_2 & R_2^2 & R_2^{z-1} \\ \\ 1 & R_{z-1} & R_{z-1}^2 & R_{z-1}^{z-1} \end{bmatrix} \tag{9}$$

CAZAC sequences of lengths 256, 625 and 900 are generated. There are 16 and 30 roots of unity for CAZAC sequences

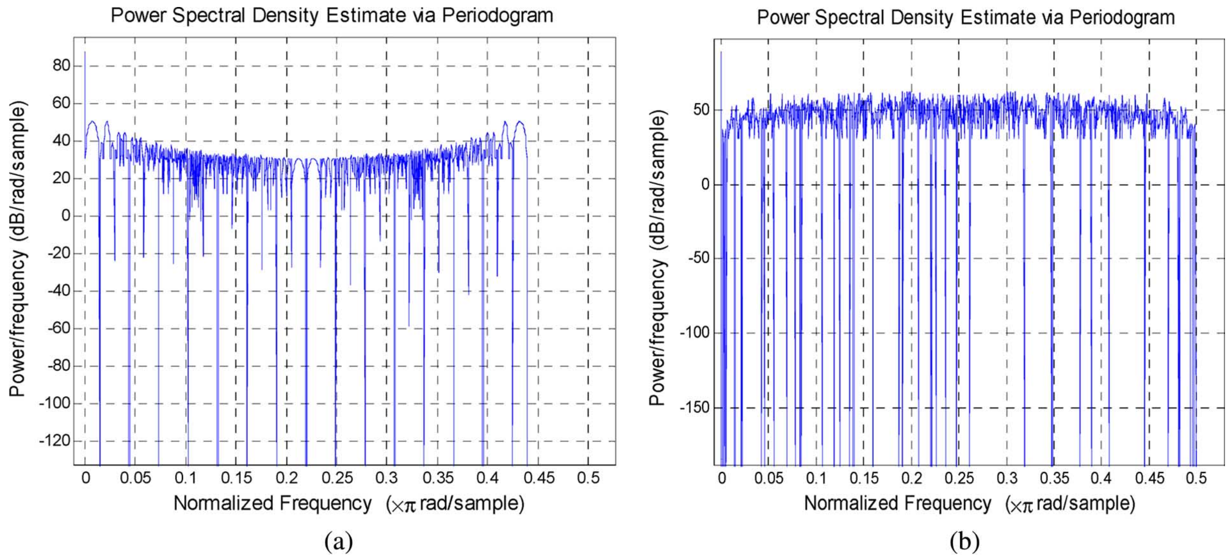


Fig. 6. Simulated Power Spectral Densities of (a) the CAZAC900 and (b) MLS1023 sequences with 4096 FFT points.

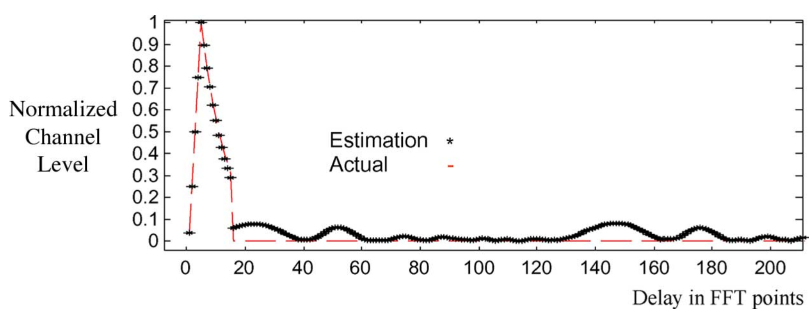


Fig. 7. Comparison of actual and estimated RA6 channel using a CAZAC sequence of length 900 at an SNR of 15 dB.

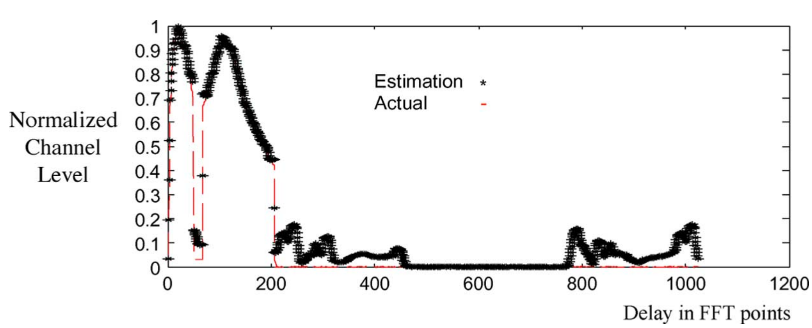


Fig. 8. Comparison of actual and estimated BU12 channel using a CAZAC sequence of length 900 at an SNR of 20 dB.

of length 256 and 900 as shown in Fig. 5. Example simulations of the Power Spectral Densities of the complex CAZAC900 sequence and MLS1023 sequence are shown in Fig. 6 for 4096 FFT points.

B. Performance of the Channel Estimator

The performance of the different training sequences generated above is investigated for different channel profiles in terms of the mean square error (MSE) for different channels with the variation of the Signal to Noise Ratio (SNR). The channel estimator works in the frequency domain according to (3)–(5). This is followed by an inverse Fourier transform to retrieve the estimated channel in the time domain. A sampling frequency of 10 MHz is selected and 1024 FFT points are used in the simulations. The Fourier transform procedure is not ideal and this results in an error floor that can be reduced by windowing, averaging the channel estimates over a long time or reducing the number of FFT points to the minimum possible.

To assist channel estimation especially at startup and for quick acquisition of the channel impulse response, the training sequence should be as high as possible On the other hand, the training sequence should not cause excessive interference to the DVB signal. The proposed low cost on-channel repeater does not clean up the signal through error correction; hence a clean signal with high SNR ($\sim$30 dB) is required at the input. A substantial amount of averaging is required to recover the training sequence from the interference represented by the DVB signal and noise. The more averaging used, the better the recovered training sequence to noise ratio. Simulations show that for quick acquisition of channel estimates and without averaging around 20 dB training sequence to noise level is needed.

For successful DVB reception, the training sequence level should be around 10 to 20 dB below the DVB failure point. However, the update rate of the channel estimator should be equal to or faster than the Doppler rate and the dynamic variations of the channel. These are conflicting requirements since to achieve a good training sequence to noise level, a long averaging time is needed which would reduce the Doppler capability of the system and a trade-off is necessary. A possibility is to allow a higher training sequence level hence allowing less averaging but at the cost of reducing the coverage of the repeater system since the training signal will act as additional interference and will cause the DVB signal to fail at a shorter distance.

An example is given below to illustrate the above tradeoff:

Assuming the acceptable maximum degradation in the DVB Carrier to Noise Ratio (CNR) to be 0.5 dB, then this would result in an unnoticeable reduction in the service area (following a simple inverse square path loss law). Let the failure point occurs at a $\mathrm{CNR} = 18$ dB and let the training sequence level be T = 10 dB below the noise at failure point:

$$\text{Then } 10\log\left(\mathrm{C}/(\mathrm{N}+\mathrm{T})\right) = 18\ \mathrm{dB}; \mathrm{T} = 0.1\ \mathrm{N} \tag{10}$$

For $\mathrm{C} = 0$ dB then $\mathrm{N} = -18.4$ dB resulting in a 0.4 dB degradation which is slightly better than the 0.5 dB maximum allowable target degradation above. The training sequence T is buried at 28.4 dB below the DVB level C. To extract the channel estimate at a reasonable accuracy, the training signal power should be 20 dB above the signal power. This means that 48.4 (20+ 28.4) dB improvement in the training signal to DVB signal ratio (TCR) is needed. This improvement can be achieved by averaging over a long time the channel estimates. The number of averages needed would be approximately $10^{4.8}$ (i.e. ~63000 times) and this comes at the cost of the Doppler capability of the system.

For the shortest sequence used CAZAC256 of 25.6 μs duration at 10 MHz, the update rate would be approximately 0.6 Hz. The system can cope with a Doppler rate of just over 0.5 Hz. The Doppler capability of the system can be improved by easing the constraints hence allowing less coverage of the repeater and fewer averages or trading off Doppler, length of echoes to be estimated and cancelled and the training sequences used.

Fortunately, the channel at the repeater is often pseudo-static, with only very slow variation with time (low Doppler frequency). Dynamic variations of the channel may however exist and the time required for channel estimation determines how fast the repeater can respond to those dynamic variations.

Examples of channel estimation simulations are shown in Figs. 7 and 8. Fig. 7 compares an estimated and an actual rural area channel (RA6) for a CAZAC sequence of length 900 at an SNR value of 15 dB. Fig. 8 The figure compares the actual and estimated channel of a bad urban COST 207 scenario (BU12)

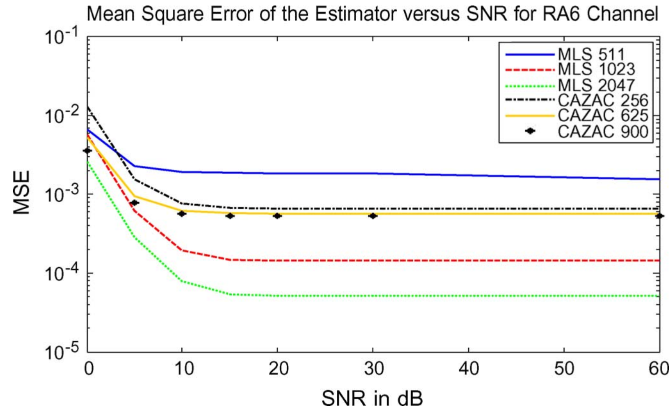


Fig. 9. Comparison of the MSE performance of different training sequences for a rural area channel.

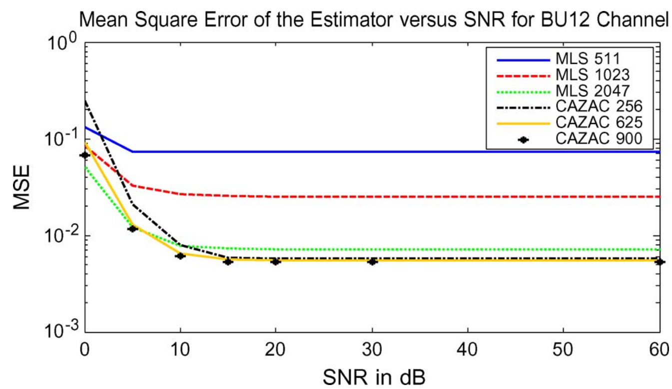


Fig. 10. Comparison of the MSE performance of different training sequences for a bad urban channel.

with a delay spread of 2.47 microseconds for a CAZAC sequence of length 900 at an SNR value of 20 dB and 1024 FFT points. The MSE value is below 5.5×10^{-3}. It is concluded that the channel power delay profile is estimated to a good accuracy. A windowing or long averaging procedure can be applied to further improve the estimation accuracy and lower the MSE value by reducing the ringing due to the FFT process. Another possibility is to ignore the tail of the estimated channel since important echo clusters are concentrated around the first half or even third of the FFT points.

Comparison of the performance of the different training sequences are shown in Figs. 9 and 10 for RA6 and BU12 channels respectively. It is concluded that in general, CAZAC sequences of shorter lengths outperform MLS sequences especially for large delay spread channels like BU12 where more than one cluster of echoes exist.

VI. Conclusions

This paper investigated the performance of an echo canceller for on-channel repeaters in DVB-T/H networks. It was shown that the presented echo cancellation algorithm based on open loop channel estimation can effectively achieve good isolation and ensure the stability of the on-channel repeater. In a 2 K system with a maximum allowable processing delay of 2 μs, the maximum number of taps is restricted to 20 at 10 MHz sampling. In this case, the isolation improvement figure of the echo canceller would be better than 20 dB for all profiles except for long channels like Bad Urban or Hilly Terrain. If 14 bits or more are used for quantization, the expected degradation caused by finite point arithmetic would be a fraction of a dB.

The channel estimation methodology is based on training sequences and the correlation principle. The training sequence is buried at low power (10 to 20 dB below the DVB failure point). This approach has the advantage of not altering the DVB signal format and offer effective estimation of the channel since the training sequence is uncorrelated with the DVB signal.

CAZAC sequences outperform MLS sequences of longer lengths especially in the estimation of long delay spread channels with more than one cluster of echoes. Recommended lengths to cover all possible environments are MLS of lengths 511, 1023, 2047 and CAZAC of lengths of 256, 625 and 900. A good compromise single training sequence for all channel environments would be CAZAC 625. The training sequences types, lengths and levels can be stored in a look up table and recalled by software in situ to match the most likely channel to be encountered.

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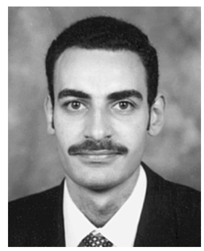

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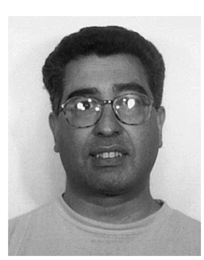

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Jeff Gledhill has over 20 years of experience in the professional broadcast industry. He has been involved in the development of technical standards such as DVB-T, as well as the design and development of equipment and silicon working to these standards. He is now a director of Videsco Limited, a company designing broadcast and communications systems.